

DRAFT

EVALUATION OF **BIOMASS-TO-ETHANOL** FUEL POTENTIAL IN CALIFORNIA

A REPORT TO THE GOVERNOR
AND THE
AGENCY SECRETARY,
CALIFORNIA ENVIRONMENTAL
PROTECTION
as directed by Executive Order D-5-99

Gray Davis, Governor



RESOURCES AGENCY

OCTOBER 1999

**CALIFORNIA
ENERGY
COMMISSION**

P500-99-017

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

Executive Summary

Introduction

In response to growing evidence that methyl tertiary-butyl ether (MTBE) is contaminating California's groundwater and surface water, Governor Gray Davis issued Executive Order D-5-99 calling for the phaseout of this gasoline additive. Appendix ES-A contains a copy of the complete Executive Order.

What Are California Agencies Required to Do?

As part of the state's response to the potential environmental and public health risks, the Executive Order requires the California Energy Commission to evaluate California's potential to develop a "waste-based or other biomass ethanol industry" and "what steps, if any, would be appropriate to foster waste-based or other biomass ethanol development in California should ethanol be found to be an acceptable substitute for MTBE."

In addition, the Executive Order requires others state agencies to undertake a series of activities to mitigate the environmental effects of MTBE and examine the environmental and health implications of ethanol use in place of MTBE.

Since the other investigations that bear on the role ethanol might ultimately play in California's gasoline supply are ongoing, this evaluation of in-state ethanol supply potential does not assume the outcomes of these other related studies.

What Is the Federal Government Doing to Promote a Biomass-to-Ethanol Industry?

The federal government has a long history of supporting research, development and commercialization activities for converting biomass-to-ethanol. More recently, President Clinton, on August 12, 1999, signed an executive order to develop and promote bio-based products such as ethanol and bio-electricity. The President also directed several federal agencies to work together to modify federal programs toward the goal of tripling the national use of bio-based products and bio-energy by 2010. Appendix III-C contains the full text of the President's Executive Order.

Major Findings and Conclusions

The Energy Commission staff's analysis shows that ethanol fuel produced from waste and residual materials offers potential for meeting the state's oxygenated gasoline needs. As a renewable fuel, biomass-to-ethanol fuel production offers a number of potential energy, environmental and economic benefits.

Creating a viable in-state ethanol industry to capture these benefits, however, poses a major challenge. The cost of producing ethanol remains high, requiring continued government price support to make it a competitive fuel additive. Developing a California ethanol industry will also require a state government role to overcome economic, technical, and institutional barriers and uncertainties. California-produced ethanol fuel will face stiff competition from out-of-state ethanol supplies and in-state petroleum products.

Commercializing new technologies for converting biomass to ethanol raises uncertainties and presents challenges that must be overcome to foster and nurture a commercial ethanol industry in California.

The lack of commercial experience with biomass-to-ethanol conversion in California and elsewhere suggests that the state would be prudent to co-fund the first several production facilities as part of a near-term demonstration effort. A demonstration would be particularly valuable to gain insight into the actual benefits and drawbacks to siting, building, and operating such facilities in California.

In addition, developing a clear biomass-to-ethanol state policy to guide and coordinate actions can help reduce the many challenges that exist in developing this industry. Supporting activities to encourage the production and use of ethanol fuel as a renewable energy source complements California's ongoing efforts to develop transportation energy alternatives.

Past Efforts on Biomass-Based Ethanol Production in California

The Energy Commission and other state agencies began work on biomass-based ethanol production and its use in transportation nearly two decades ago.

Beginning in 1980, several demonstration projects were conducted to investigate the practicality and cost effectiveness of alcohol motor fuels. While this early work showed that ethanol production was potentially viable in the state, it became evident that the economics for in-state production were not competitive with corn-derived ethanol from the Midwest.

More recent work at the Energy Commission has identified a wide variety of biomass resources in California that may be suitable feedstocks for ethanol production.

Biomass-to-Ethanol Production in the United States and California

Nearly all the ethanol used as fuel in the United States today is produced from corn-based facilities in the Midwest. Currently, one small ethanol facility in California is operating, using beverage industry waste, with a capacity of 6 million gallons of ethanol a year.

Government Incentive Programs

The economics of ethanol fuel in the United States are influenced by favorable federal tax provisions, which effectively reduce the retail price of ethanol by 54 cents per gallon. A federal income tax credit is also in place, and a number of states offer additional state tax incentives. Without these tax provisions, ethanol would probably not be produced at today's quantities in the United States motor fuel market.

California has several state programs that impact the use of certain waste feedstocks. A tax credit is available to farmers who divert rice straw from open burning through the Rice Straw Utilization Tax Credit Program. The program provides a \$15 per ton (of rice straw) tax credit, capped at \$400,000 annually. In addition, the Rice Straw Demonstration Project Fund provides cost-sharing grants for promising projects to utilize rice straw.

For the conversion of municipal solid waste (MSW) to energy, a limited (non-financial) diversion credit is available through the California Integrated Waste Management Act (1989) to assist local municipalities in meeting their 50 percent waste reduction goals.

MTBE Phaseout and Demand for Ethanol in California

With the phaseout of MTBE, ethanol may be required as a gasoline additive to meet federal and state requirements in gasoline. The uncertainty surrounding regulatory decisions will affect the use of ethanol in the future.

As displayed in Figure ES-1, if ethanol is used to replace MTBE, the California demand for ethanol may be as low 148 million gallons of ethanol in 2003 or as high as 1.15 billion gallons a year. Three California projects are in the active planning stages and, if constructed, could produce about 44 million gallons of ethanol a year by 2004. Thus, if ethanol is used to replace MTBE, most of it will initially be supplied from out-of-state sources, primarily corn-based ethanol from the Midwest.

California's Biomass Resources

California generates an estimated 51 million bone dry tons of gross waste and residual biomass resources annually from its large agricultural industry, forests and large volumes of municipal solid waste materials, that offer potential supply sources for producing ethanol.

Several factors will affect how much of California's biomass resources will be available commercially. These factors include the high costs to collect and transport some feedstocks and the markets that now exist for some feedstocks. The amount of feedstocks economically available to produce ethanol will change with market conditions.

Other biomass resources to produce ethanol may exist, such as substantial livestock manure resources and out of state residues. These resources, however, will require additional study.

The three primary categories of waste and residual biomass resources in California include forest wastes (42 percent), municipal solid wastes (31 percent) and agricultural residues (27 percent).

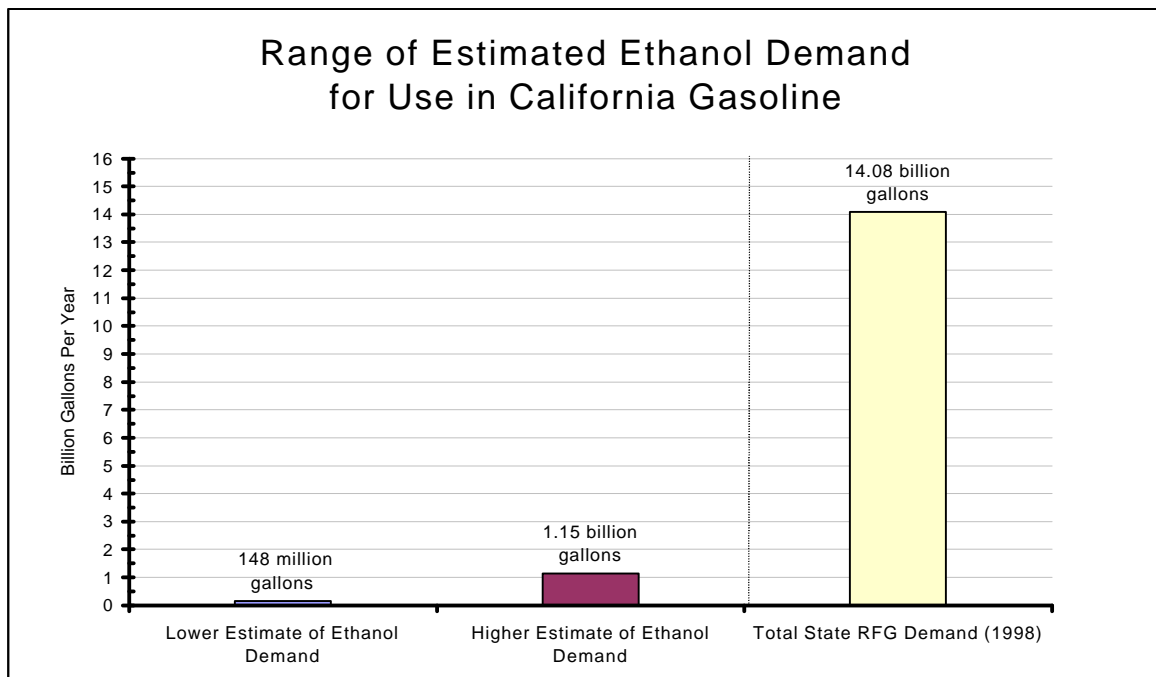


Figure ES-1

Source: California Energy Commission

California's Potential Biomass Energy Crops

Biomass energy crops, grown for their energy value, represent another approach to supplying feedstocks for ethanol production. While waste-based feedstocks receive greater attention for proposed near-term ethanol production, energy crops represent a potentially larger source of longer-term supplies for ethanol production, but high costs must be overcome.

Currently, there are no plans in evidence to produce ethanol from California-grown energy crops. Limited studies of energy crops, have identified sweet sorghum and eucalyptus as possible supply sources in the future.

Regulatory Requirements for Siting a Biomass-to-Ethanol Facility in California

Siting a biomass-to-ethanol facility in California is a complex process, which can take 12 to 18 months or longer. The location of the site and its size will determine who has jurisdiction and the responsibility as lead agency for preparing an environmental impact report and determining whether the project complies with the California Environmental Quality Act.

Ethanol Production Potential from Biomass Resources

The estimated physical upper limit for ethanol produced from California's waste residues exceeds 3 billion gallons a year. The actual amount of residues that are available, however, is significantly lower once economic, technological, and institutional factors are considered.

Many studies of biomass-to-ethanol demonstration projects were previously undertaken in California but did not advance beyond the feasibility phase. Several promising technologies to convert biomass-to-ethanol, electricity, and other products are being developed, and significant improvements in ethanol production costs are expected as the technologies mature.

Biomass-to-Ethanol Project Economics

The economics of a biomass-to-ethanol project are difficult to assess completely because biomass-to-ethanol technologies are still in the demonstration phase.

High capital costs associated with the non-commercial status of biomass-to-ethanol technology contribute to high risk financing. Feedstock costs represent the largest portion of the total costs, and thus the availability of low cost feedstocks is critical for producing ethanol at low cost. Other project economics are subject to many unknowns and will vary with plant size, location, and many other variables.

A collocated ethanol production facility and biomass power plant has several economic advantages. Both facilities share the cost of processing feedstocks. The ethanol facility can contract with the biomass power plant to manage feedstock procurement and inventory, which reduces the fixed operating costs for both facilities. The ethanol plant can also process feedstocks that would be burned in the biomass power plant and provide lignin as fuel for the power plant (lignin is a by-product of converting biomass-to-ethanol). Ethanol production cost savings up to 20 percent are possible with collocation of a biomass power plant with an ethanol facility.

Ethanol's value in the gasoline blending market is determined by the price of competing gasoline (or oxygenates), its octane value, and tax incentives provided at the federal and

state level. Thus, as gasoline prices in each state vary, and as tax credits vary, the price of ethanol will vary.

Potential Public Benefits from a Biomass-to-Ethanol Industry

A number of potential public benefits may be derived from a biomass-to-ethanol industry in California.

Ethanol is an alternative fuel because it is not derived from petroleum sources. As an alternative fuel, ethanol can help California meet state and federal energy security goals, as outlined in the National Energy Policy Act of 1992. Furthermore, ethanol is a renewable fuel, meaning that its feedstocks (generally plant materials) are not derived from non-renewable fossil fuel sources and offer an effective option for reducing greenhouse gases that may contribute to global climate change.

Studies have shown that greenhouse gas reductions are possible with ethanol produced from biomass as compared to non-renewable fuels on a full fuel cycle basis. Based on Argonne National Laboratory analyses, ethanol in the form of E-85 derived from cellulosic biomass (e.g., agricultural residues or MSW) can reduce carbon emissions in the range of 80 to 85 percent. In contrast, current corn-derived ethanol, in the form of E-85, achieves about a 22 percent reduction in carbon emissions.

Traditional means of disposing of large quantities of agricultural and forest wastes have been accomplished through open-field burning, which impacts air quality. Because of this concern, open burning of rice straw is being phased out. The state is seeking alternatives to this practice, such as converting the rice straw to ethanol, thereby reducing or eliminating the need to open burn.

Similarly, forest residues are being open-field burned. In an effort to improve forest health and reduce the risk of catastrophic wildfires, forests are being mechanically thinned. The conversion of forest residues to ethanol provides a potentially viable alternative to burning.

Converting MSW (including paper waste, yard waste, etc.) to ethanol would reduce the volume of waste streams that are now deposited in landfills. In addition to other diversion strategies, such as recycling and composting, waste-to-ethanol may be an attractive option.

Another benefit that could arise if a biomass-to-ethanol industry develops in California is the creation of a new industry that could provide jobs and increased tax revenues for the state.

Potential Investment Risks

A number of risks exist that could impact the development of a biomass-to-ethanol industry in California.

The rate at which cellulosic biomass conversion technologies advance will impact ethanol production costs. California-based ethanol projects are looking at converting cellulosic feedstocks, a technology that differs from traditional starch and sugar conversion technologies. Consequently, if cellulosic conversion technologies advance slowly, higher ethanol production costs will likely affect a California biomass ethanol industry adversely. The reverse is also true.

Delivered feedstock prices have a significant impact on the cost to produce ethanol. Higher feedstock prices could make a California biomass ethanol less competitive with other sources of ethanol (i.e., Midwest corn-based) and restrict the size of a California industry.

Regulatory decisions, both by the State of California and the federal government, also will impact the ethanol market. In particular, the outcome of the federally mandated use of oxygenates in gasoline will substantially impact the size and duration of a California ethanol market. Without clear evidence of a significant ethanol market, production plant financing will be difficult to obtain.

Recommendations to Foster Biomass-to-Ethanol Development in California

Based on the evaluation of biomass-to-ethanol fuel potential in California, the Energy Commission staff recommends that the state take several actions to develop a longer-term state policy and other strategies.

These actions are broken into four categories as follows: 1) policy, 2) research, development and demonstration (RD & D), 3) market development and commercialization, and 4) further study needs. These actions represent a prudent approach to formulating a policy to guide state investment in this industry, which is now in the embryonic stage.

With regard to policy steps, California should adopt a biomass-transportation fuels energy policy that is consistent with Energy Commission programs and goals for the transportation sector. In addition, an interagency task force should be convened to establish and implement an integrated California Biomass Policy in response to several issues that go beyond the energy agenda of the California Energy Commission. The Governor, the California Resources Agency, or California Environmental Protection Agency should identify this task force.

With regard to RD&D, California should support demonstrations of several biomass-to-ethanol facilities to establish the technical and economic feasibility of waste and non-waste biomass-to-ethanol facilities. Further, the state should support RD& D to improve biomass feedstock collection, conversion and utilization. The appropriate financial mechanisms and extent of funding need to be determined.

With regard to market development and commercialization steps, California should study and determine the appropriate forms of state financial and non-financial assistance to support commercialization of the industry, should demonstration projects prove successful.

Finally, with regard to further study needs, California needs to assess and quantify the public benefits associated with the emergence of this industry to provide the rationale for public policy and public resource commitments in the longer-term.

How Was This Report Reviewed?

This report was reviewed by a technical Peer Review Group of experts who reviewed an earlier working draft version of this report. Appendix ES-D provides a list of the technical Peer Review Group members. The technical experts represent a diverse panel of individuals with particular knowledge and involvement in the field of biomass, ethanol and alternative fuels.

A public workshop was held on September 10, 1999. The Energy Commission staff received comments and input on the report and potential recommendations were discussed. Over 40 people attended the event, and a total of 18 presentations were made. Appendix ES-B summarizes comments received at this workshop.

The Energy Commission will hold public hearings on November 19, 1999 and again in December to solicit additional input as the report evolves. The final report is due to Governor Gray Davis and the Secretary for Environmental Protection on December 31, 1999.

How Is This Report Organized?

This report has been organized for a general audience, with the technical details and documentation for the chapters in a separate volume of Appendices. The following describes the contents of each chapter:

Chapter I, “Steps to Foster Biomass-to-Ethanol Development in California,” examines optional steps in a “pro and con” format and identifies the “appropriate steps” to foster biomass-to-ethanol development in California. Appendix I-A contains the technical details and documentation on which this chapter is based.

Chapter II, “Ethanol as a Fuel - Background,” summarizes the history of ethanol as a motor fuel and the role of federal and state tax incentives in fostering an ethanol market. This chapter also discusses federal and state air quality regulations affecting the use of ethanol, the current status of ethanol production and use, and the role of ethanol in the phaseout of MTBE. Appendices II-A and

II-B contain the technical details and documentation on which this chapter is based.

Chapter III, “Waste Biomass Resources in California,” defines and describes biomass, waste biomass and residues identified as candidates for ethanol production. In addition, estimates of the physical resource potential in California for various wastes and residual biomass categories are discussed. The economic and environmental factors and challenges, including competing markets and alternative disposal options affecting the viability of ethanol production, are also examined. Appendices III-A through III-C contains the technical details and documentation on which this chapter is based.

Chapter IV, “Biomass Crop Resource Potential in California,” examines the potential for producing ethanol in California from energy crops. It identifies different types of crops that are candidate feedstocks for ethanol production, reviews previous studies of the potential for energy crop-based ethanol production in the state, and discusses key factors that affect the prospects for achieving this potential.

Chapter V, “Biomass Conversion,” describes the most competitive current technologies and probable improvements to increase the rate of conversion, yields and efficiency of ethanol production, electricity, and coproducts from urban, agricultural, and forest wastes. The chapter also surveys the various technologies for converting biomass to ethanol, research on methods to improve them, and possible features of a mature biorefinery industry, including opportunities to lower the costs of ethanol produced. Appendix V-A contains the technical details and documentation on which this chapter is based.

Chapter VI, “Biomass-to-Ethanol Production Potential in California,” develops estimates of the maximum ethanol production potential in California and what is producible after addressing key technological, economic, and institutional issues. Appendices VI-A through VI-C contain the technical details and documentation on which this chapter is based.

Chapter VII, “Economic Evaluation,” assesses the economics of biomass-to-ethanol production in California compared with obtaining ethanol from conventional sources. The analysis includes a number of different production scenarios, which incorporate different feedstock and process options along with other implications such as employment. Appendices VII-A through VII-C contain the technical details and documentation on which this chapter is based.

Additionally, in a separate report several appendices provide additional information and technical details of key topics. Because of the size and number of appendices, they have been printed separately from the main body of the report. The appendices are listed here for reference:

Appendix ES-A	Governor Davis' Executive Order D-5-99
Appendix ES-B	Summary of September 10, 1999 Workshop
Appendix ES-C	Glossary of Terms
Appendix ES-D	Peer Review Group List
Appendix I-A	State Incentives, Initiatives and Programs
Appendix II-A	Current Production Capacity
Appendix II-B	Ethanol Demand
Appendix III-A	Waste Biomass Resources in California
Appendix III-B	State Rice Straw Utilization Programs
Appendix III-C	President Clinton's Executive Order
Appendix V-A	Biomass Conversion Options
Appendix VI-A	Composition and Yields of Biomass Resources
Appendix VI-B	Location of Solid Waste Handling Facilities in California
Appendix VI-C	Requirements for Siting a Biomass-to-Ethanol Facility
Appendix VII-A	Evaluation of Feedstock Costs
Appendix VII-B	Evaluation of Ethanol Production Costs
Appendix VII-C	Ethanol Market: Current Production Capacity Future Supply Prospects and Cost Estimates for California

CHAPTER I

**EVALUATION OF STEPS TO FOSTER
BIOMASS-TO-ETHANOL
DEVELOPMENT IN CALIFORNIA**

I. Evaluation of Steps to Foster Biomass-to-Ethanol Development in California

Introduction and Context

This chapter examines a menu of possible actions, in a “pro and con format,” and provides recommendations to assist decision makers in determining what, if any actions, should be taken to foster biomass-to-ethanol development in California.

The menu of possible actions was developed from study findings, past and present actions taken by other states, comments of peer reviewers, testimony at the September 10, 1999 public workshop, written comments and Energy Commission experience with technology development. The possible actions have been categorized as follows: 1) policy development, 2) research, development and demonstration, 3) market development and commercialization, and 4) further study needs.

Evaluation of Possible Actions

Policy and Program Development Options

The staff received written comments and testimony that indicated the need for a policy directed at the state’s biomass resources. Five optional policies are presented below, including a “No Action” option based on the staff analysis.

Many of the policy actions raised encompass policy areas outside of the Energy Commission’s transportation fuels policy charter. Specific mention was made of biomass, biomass-to-ethanol, biofuels, biomass to energy, biomass power (electric), renewables, and waste biomass policies.

Through an interagency task force, develop and adopt a “biomass” policy that will focus on all of the state’s waste and potential non-waste (energy crop) resources. The policy should encourage developing markets beyond those that might be considered to meet fuel supply and diversity needs and other California transportation energy objectives.

Pro- A “biomass” policy would assist the process of creating new markets for California’s waste biomass resources. Ethanol would be only one of several potential products derived from waste resources that are based on identified and future potential markets.

This policy would address the outstanding issues associated with sustaining the biomass-electric power industry in the state. Other new and perhaps higher value products would emerge in the building materials, chemical, food, fertilizer and pharmaceutical markets,

better assuring that an ethanol industry will emerge. This multiple market approach to public policy of “don’t put all your eggs in one basket” is preferable to a focused biomass-to-ethanol policy.

Con- This policy would likely require the state to continue committing resources. It will be time consuming and challenging to gain consensus on a yet to be defined broad policy affecting the development of a biomass industry.

Develop and adopt a biomass-to-ethanol policy to guide state actions involving production of ethanol from biomass resources and use of ethanol in California’s transportation sector.

Pro- When produced from in-state waste resources, ethanol has the potential to contribute to solving various disposal problems in the state, such as open burning of agricultural and forestry residues, while providing an alternative to MTBE in California cleaner-burning gasoline.

During the 1990s, California has become a “fuel island” because of unique gasoline specifications, making the state particularly vulnerable to supply disruptions and constraints. Developing in-state ethanol production will better assure that we can meet our ethanol supply needs, both as a gasoline-blending component and in neat applications (i.e., E85).

Currently, California does not have a policy to guide ethanol-related state activities.

Con- It is unclear whether using waste biomass resources to produce ethanol is either viable or environmentally superior to other waste disposal or waste conversion options. Creating a biomass-to-ethanol policy will not assure that an ethanol industry will develop in the state. The state may be better off waiting until more information is available on the benefits and costs of a California biomass-to-ethanol industry.

Through an interagency task force, develop and adopt a “biomass power” policy to protect the existing biomass-to-electricity industry and thus increase the likelihood that collocated power/ethanol projects currently in planning stages will emerge.

Pro- This policy would forestall the closure of existing biomass power plants that have marginal or negative economics in California’s deregulated electricity market. These biomass power plants have systems to deliver waste feedstocks, as well as other infrastructure and actual hardware on the ground. A biomass-to-ethanol industry could use these systems collectively as a “springboard.” This policy would protect the existing industry, a crucial step in leveraging new capital for biomass-to-ethanol facilities.

Con - This policy requires additional support beyond that provided under Assembly Bill 1890 and has the potential to obligate the state for additional financial support of this

industry. The opinion of the forest products industry seems to be split regarding the feasibility of waste forest residues to power/ethanol production as a business option.

Develop and adopt a “biofuels” policy that would consider opportunities involving all liquid and gaseous fuels derived from biomass that could serve California’s transportation energy needs and environmental goals.

Pro - This policy would provide a framework to develop an industry with a broader slate of fuel and possibly coproduct options. Methanol, methane and other fuels derived from biomass could emerge in advance of cellulose-based ethanol. Favorable economics and timeliness of the options would be recognized.

This policy would allow for additional fuel options that could reduce carbon emissions and help meet international global climate change goals. Such a policy would help California if the federal government decides to direct states to meet global climate change goals.

Con – This policy is too restrictive and neglects other important sectors of the state’s economy that could benefit from broader market development under a “biomass” policy. Biofuels may not be the most economic products that can be derived from biomass resources.

Do not develop and adopt a policy at this time.

Pro - It may be too soon to develop a policy involving comprehensive actions to foster a waste-based or other biomass-to-ethanol industry. The technology is not yet proven at a commercial scale. If ethanol is needed to meet California’s gasoline requirements, ethanol can be imported from the Midwest for many years. The state’s existing policies and programs in the various state agencies are adequate, if these functions are coordinated.

Con - This policy could delay or stall the emergence of a biomass-to-ethanol or biomass industry in California. It could delay the many benefits—environmental, forest health, and disposal—that would be associated with such an industry in the longer-term, if demonstration projects prove the commercial readiness of waste biomass-to-ethanol and associated coproducts. Furthermore, not developing a policy could hasten the early demise of the biomass power industry in California and slow the process of collocating ethanol plants with these facilities.

Research Development and Demonstration Options

Provide direct financial support to biomass-to-ethanol facilities built in California.

Pro - This action would commit the state as an active partner in the demonstration and prove-out of technical and economic feasibility of the first several facilities in California. This policy would send a signal to the industry and financial institutions. Funding would

be seen as a safety net to the biomass power industry if some of these funds were directed to collocated biomass power/ethanol projects.

Con - The level of funding for 2-5 projects could range upwards of \$100 million. Some lower level of funding might be adequate to meet the state's objective while still leveraging needed private capital for the first few projects.

Provide funding for research programs to address remaining technology development needs such as reducing costs of feedstock collection, preprocessing and transport.

Pro - This policy will help reduce the cost of feedstocks and improve the economic feasibility of waste biomass-to-ethanol facilities. If located in California, a research program would address feedstock handling and processing issues unique to the state.

Con - The federal government is already applying significant resources in this area. California does not need to pursue its own course because the research in progress has broad applicability. If any action is needed, the California Resources Agency or California Environmental Protection Agency should prioritize specific technology development activities.

Pursue development of advanced engine technologies that can use ethanol and other fuels derived from biomass. The technologies include emerging direct injected engines, hybrid-electric and fuel cell vehicle applications.

Pro – Manufacturers are spending hundreds of millions of dollars on advanced engine technologies without considering ethanol and other alternative fuels. With a modest level of funding through its transportation energy-related programs, the Energy Commission could help ensure that the industry makes these technologies available in the future.

Con – A modest level of funding may be insufficient to influence evolving advanced technologies. The state should not commit significant amounts of funding for ethanol-only applications this soon. Limited resources might be better directed at a variety of alternative fuels in cooperation with the federal government and industry—given the current uncertainty of a biomass-to-ethanol industry in California. The industry does not normally prefer California-specific policies or mandates because the larger market is the U.S. A commitment by the state through a long-term technologies and fuels policy will be required to win industry support.

Develop an educational program to heighten public awareness of the environmental, energy and waste disposal benefits of a biomass-to-ethanol industry.

Pro – This would improve public awareness and support for waste to energy, transportation fuels and other products derived from waste biomass resources. If focused on transportation fuels, this policy would enhance the use of ethanol in flexible fuel

vehicles currently entering California in large numbers. The demand for ethanol would grow and enhance opportunities for waste and non-waste biomass-to-ethanol projects.

Con - It is too early to promote this industry given the uncertainty of its future. Educational activities should wait until demonstration projects have proven the feasibility of the biomass-to-ethanol industry. The California Resources Agency or California Environmental Protection Agency should promote using waste resources in energy and non-energy markets as a broader state goal.

Market Development and Commercialization Options

Provide low interest loans for biomass-to-ethanol facilities.

Pro – If the state provides low interest financing, it removes some of the risk that financial institutions would assume. This policy may be the “jump-start” to the industry that project and industry proponents are looking for. More preferable than loan guarantees.

Con – This is a risky approach because the biomass-to-ethanol technology is commercially unproven. Defaults on the loans may result in substantial financial losses to the state.

Provide state-backed loan guarantees to construct biomass-to-ethanol facilities.

Pro - Perhaps the quickest way to get financial institutions to back projects. Would likely prevent delays in project financing, thus encouraging biomass-to-ethanol facilities to emerge early.

Con - Removes too much risk from financial institutions and thus would encourage premature funding or funding of marginal projects by financial institutions. The federal government supported ethanol projects in the 1980s that failed, illustrating the shortcomings of this approach.

Provide ethanol production subsidies (producer credit) to encourage ethanol production while markets develop.

Pro- An alternative to loan guarantees which would provide a buffer against the early high cost of producing ethanol. This mechanism can be capped at a total dollar value or on a per facility basis. As used by several Midwest states, this policy has proven successful when used in concert with other incentives/subsidies.

Con - Does not remove the financial risk to banks. May be more suited to the emerging industry using proven technologies. Might not be the best approach for demonstration projects meant to prove technical and economic feasibility.

Provide a mix of incentives. This mix should include fuel and sales tax exemptions; producer tax credits, other tax credits, and bonds for at least ten years.

Pro - A mix minimizes the financial risk to the state. It is an aggressive approach meant to stimulate an industry to develop quickly.

Con - It is too soon to propose a mix of incentives given the infant status of the industry. It is more appropriate to apply a mix of incentives such as is done for the corn-to-ethanol industry in the Midwest.

Identify potential markets 10 and 15 years out, as a mechanism to assure capital investments needed to start the industry.

Pro - Identifying markets, especially for the long-term, is key to the success of projects and developing industries. A clear vision, under an adopted long-term policy, to encourage markets at 10 and 15 years will reduce the financial risk and thus the reluctance of the financial community to fund projects.

Con- It is difficult to identify emerging markets clearly, especially coproduct markets. A better state policy would be to encourage and participate in research to create products and identify potential markets as an alternate strategy.

Develop a policy to create a more consistent and integrated solid waste collecting, sorting and processing infrastructure to stimulate waste conversion market opportunities.

Pro – This would help ensure that municipal solid waste streams everywhere in the state are available for a biomass industry. The state of Washington used this kind of initiative and demonstrated that markets emerge in response.

Con - Mandated collection occurs at the local level in many places now. There is no assurance that such a program will stimulate the siting of collocated municipal waste recovery/ethanol production facilities. Other higher value markets may bid away the feedstock. This policy would have to win support from numerous local government officials and their constituencies.

Create a market for ethanol in California as Brazil has done. Stimulate the use of dedicated or flexible fuel vehicles as well as the possible use of high-level ethanol blends such as E22.

Pro - Ethanol capable (E85) flexible fuel vehicles are being sold in California today. The infrastructure needed to support flexible fuel vehicles or dedicated vehicles, such as retail pumps for dispensing E85, represent a minor additional cost to the infrastructure costs that will be required if ethanol is used as a substitute for MTBE in California cleaner-

burning gasoline. A flexible fuel vehicle allows consumers to switch fuels and thus represents a mechanism to mitigate gasoline price volatility by switching to E85.

Con – The Clean Air Act and California Air Resources Board’s requirements prohibit the use of E22. California’s existing federal waiver limits ethanol to 10 volume percent. Further, vehicles manufactured in the United States are not designed for this high oxygen content, nor are dedicated ethanol vehicles being produced for sale in the United States. The Corporate Average Fuel Economy regulations favor flexible fuel vehicle production over dedicated vehicles for generating new vehicle fuel economy credits. E85 may be priced higher than gasoline, thus discouraging the purchase of dedicated vehicles and making it unnecessary to site pumps at retail outlets.

Adopt a renewable fuel standard for ethanol in gasoline at prescribed levels such as 5.7 to 10 volume percent.

Pro – This would create an ethanol blending market with assured volumes ranging from 750 million to 1.1 billion gallons of ethanol in (2003). This option assures that California will promote fuel diversity and avoid backsliding on fuels diversity, which will occur with the ban on MTBE. Would stimulate investment in California ethanol facilities because of the large assured future market.

Con - Inconsistent with the California Air Resources Board proposed cleaner-burning gasoline regulations which would give oil companies the option to blend at any level of oxygenate but not to exceed a proposed 3.7 weight percent cap (10 volume percent). Would raise the cost of gasoline to consumers. Given the current state of ethanol production in California, this large demand could only be met by imported Midwest or Caribbean ethanol for some time to come.

Further Study Options

Undertake a study in conjunction with the financial community to identify the most appropriate forms of financial assistance for an emerging biomass-to-ethanol industry. The study would identify how to maximize the leveraging of private capital at some time after technical and economic feasibility of initial projects has been established.

Pro- Provides a mechanism to protect the state’s investment in an emerging industry. By studying and selecting the most appropriate financial tools, the state can minimize its exposure to unwise investments and leverage commitments from private investors and financial institutions once technical and economic feasibility are proven.

Con- This study would interfere with the private sector financing process and compromise confidentiality of projects emerging at this time or in the near future.

The state should conduct a study, under interagency sponsorship, to determine the availability, costs to collect, and the sustainability of California's various waste-biomass resources. The study would identify the economically retrievable quantity in all waste resource sectors and determine possible scenarios for using these resources in energy production and other markets.

Pro- This approach would establish a comprehensive body of information, which the private sector would use to develop commercial projects for numerous markets.

Con- This approach would duplicate efforts that have been underway for many years among the various agencies. The private sector can get the information they need from specific agencies. The economics of biomass resources are only one aspect of a site specific project economic feasibility study. The best strategy is to approach overall project economics on a site-specific basis. This study belongs in the domain of the private sector.

Conduct a cost/benefit analysis to quantify the value of a biomass-to-ethanol industry to the state.

Pro- Various public benefits can be qualitatively and in some cases quantitatively evaluated for a California biomass-to-ethanol industry. However, no definitive study of these benefits has yet been conducted. Such a study would be helpful in determining the appropriate levels of public investment, given the value of public benefits determined.

Con- Historically, these studies have been subjective in determining the values of specific public benefits. Further, these analyses often fail to achieve a broad consensus, which can be critical to the usefulness of such information. The results may or may not validate specific levels of existing or proposed public investment.

The long-term potential for supplying transportation fuels from energy crops grown in California should be more definitively investigated by appropriate federal and state agencies and institutions.

Pro- In addition to waste-based feedstocks, energy crops represent the "other" category of potential ethanol feedstocks, which have been evaluated in response to the Governor's Executive Order. While the current study emphasizes the waste- and residue-based feedstocks, energy crops could provide future opportunities for California to extend its supply sources of biomass-based ethanol to include certain crops produced as part of the state's overall agricultural industry.

Con- This study could confirm that energy crops are not a viable source of feedstocks, that favorable economic, energy, environmental and resource conditions for energy crops do not exist in the state. The near-term preference for using waste-and residue-based feedstocks will likely prevail over energy crops.

Recommendations to Foster Biomass-to-Ethanol Development in California

The Energy Commission staff recommends that the state undertake the actions outlined below, which have been consolidated, where appropriate, from the foregoing discussion. These recommendations represent the best judgement of actions that are appropriate at this time regarding developing a biomass-to-ethanol industry in California.

The staff used the following questions in selecting these recommendations: The staff used the following questions in selecting these recommendations:

- Can actions be identified which guarantee, with a fair degree of certainty, the success of a biomass-to-ethanol industry in California?
- Can a reasonable sequence of actions be identified to examine the possibility of a biomass-to-ethanol industry without wasting state resources?
- Can the actual costs and risks associated with the actions be estimated?
- Can risks and/or costs of some future industry be identified by considering broader uses of waste biomass other than ethanol?
- Can actions be identified that lead to a viable, self-sustaining industry (i.e., one without continuing government support).

Policy Recommendations

Regarding the Policy Recommendations, the testimony and written comments concurred with the staff findings that a broader interagency forum is needed to establish a California Biomass Policy. This policy is broader than the authority of the Energy Commission that focuses on the state's energy supplies and energy policy.

This forum should use the missions, goals and authority of state agencies to develop and recommend a broad state policy directed at developing California's waste biomass resources. An oversight agency -- identified by the Governor, the California Resources Agency or California Environmental Protection Agency -- should take the lead in this effort.

The following policy recommendations are specific suggestions that this oversight agency should implement:

- Develop and adopt a biomass-transportation fuels energy policy, which is consistent with the Energy Commission goals for the transportation sector. This policy should consider adopting carbon reduction goals that are consistent with international treaties and possible federal government actions implied by those treaties. The policy should

also study and, if feasible, propose adopting fuel diversity goals for California's motor vehicles.

- Develop, adopt and periodically review a position on the long-term need for the federal alcohol fuels subsidy, as it would effect the emergence of a biomass-to-ethanol or biomass-to-transportation fuels industry in California.
- Consider changing the 10 percent waste diversion credit limit that applies to "transformation" technologies as defined in the Integrated Waste Management Act (Public Resources Code sections 40201 and 41783).

Research, Development and Demonstration Recommendations

- Pursue joint funding opportunities that support demonstrations of several biomass-to-ethanol projects in the state. Financial mechanisms should be identified that best suit the specific projects selected. The projects should be administered by public/private partnerships.
- Develop and share the costs of a program through a private/public partnership directed at improving the collection, transportation and processing of feedstocks for biomass transportation fuels production, as well as other related research areas.
- In cooperation with and jointly financed by the federal government and manufacturers, initiate advanced engine development projects that use biomass-derived transportation fuels specific to California's need for high efficiency, low carbon and low emission vehicle technologies.

Market Development and Commercialization Recommendations

- Study and recommend the most appropriate forms of state financial and non-financial assistance and other actions to support market development and commercialization activities should demonstration projects prove that biomass-to-ethanol projects are technical and economically feasible.

Further Study Needs Recommendations

- Develop a method to determine the cost and public benefits associated with developing biomass-to-ethanol and biomass to transportation fuels industry in California.

CHAPTER II

ETHANOL AS A FUEL --BACKGROUND

II. Ethanol as a Fuel -- Background

Introduction

This chapter summarizes the history of ethanol as a motor fuel, the role of federal and state tax incentives in fostering an ethanol market, federal and state air quality regulations affecting ethanol use, the current status of ethanol production and use, and the role of ethanol in the phaseout of MTBE.

What is the History of Ethanol as a Motor Vehicle Fuel?

Since the earliest days of the automobile, alcohols have been used as motor fuels. The term alcohol has often been used to denote either ethanol or methanol as a fuel. One of the earliest alcohol fuel advocates, Henry Ford, adapted his Model T to run on either gasoline or alcohol and sponsored alcohol fuel conferences.(1)

In 1917, Alexander Graham Bell proclaimed the benefits of alcohol fuel in a commencement address published in *National Geographic*.(2) The great inventor noted the variety of feedstock sources for alcohol production, including “sawdust, a waste product of our mills...corn stalks, and in fact almost any vegetable matter capable of fermentation...growing crops and even weeds...the waste products of our farms...and even the garbage of our cities.” When gasoline became readily available and inexpensive, however, the hopes of such early advocates for achieving significant markets for alcohol fuels were dashed.

In the 1930s, the Great Depression brought a new interest in farm products, and ethanol and gasoline were blended for the first time. The American Automobile Association conducted the first testing program in 1933. Also during the 1930s, ethanol fuel gained market shares in other countries such as Germany, Brazil, New Zealand and France.

With the oil crises of the 1970s, ethanol became more established as an alternative fuel. Various countries, including Brazil and the United States, undertook national programs to promote domestically-produced ethanol. In addition to the energy rationale, ethanol/gasoline blends in the United States were promoted as an environmentally-driven practice, first as an octane enhancer to replace lead. More recently, ethanol has been used as an oxygenate in clean-burning gasoline to reduce vehicle exhaust emissions.

Brazil has promoted ethanol from sugar cane as an alternative fuel, used both in ethanol/gasoline blends and in dedicated ethanol vehicles. As of 1996, after over twenty years of varying degrees of government support for ethanol, Brazil was using about 3.5 billion gallons of ethanol annually to supply about 40 percent of its automotive fuel use. (3, 4) Other countries currently producing and using ethanol fuel include France, Korea, Mexico, Australia, Canada and Sweden.

In the United States, ethanol supplies roughly one percent of the highway motor vehicle fuel market -- in the form of ethanol/gasoline blends. Currently, most of this ethanol is used in a 10 percent blend with gasoline traditionally referred to as “gasohol,” a term which is being replaced with “ethanol/gasoline blends” or “E10.” Lower percentage blends, containing 5.7 percent or 7.7 percent ethanol are also being used in some areas to conform with air quality regulations affecting the oxygen content of reformulated gasoline.

Besides the ethanol/gasoline blend markets, ethanol has other motor fuel applications that represent even larger potential markets in the U.S. and California. These include:

- Use as E85, 85 percent ethanol and 15 percent gasoline, in specially prepared vehicles. Some new gasoline vehicle models are being produced as flexible fuel vehicles (FFVs), capable of using E85 or gasoline in any combination. In the past, dedicated light-duty vehicles using E85 only have been demonstrated.
- Use as E100, 100 percent ethanol with or without a fuel additive. Demonstration fleets of heavy-duty buses and trucks with specially-designed engines adapted from diesel engines, have been operated on this fuel.
- Use in Oxydiesel, typically a blend of 80 percent diesel fuel, 10 percent ethanol and 10 percent additives and blending agents. This fuel is being demonstrated in fleets of buses with unmodified diesel engines.

Have Federal And State Tax Incentives Fostered An Ethanol Market?

Tax incentives have played a critical role in fostering an ethanol market in the United States. This issue has been and will continue to be debated at the federal and state levels.

Federal Tax Incentives

In 1978, Congress enacted the first tax incentive for ethanol, a fuel excise tax exemption. Originally, this incentive was a full exemption from the 4 cents per gallon gasoline tax that applied at the time. Currently, two types of federal tax incentives apply to biomass-derived ethanol sold as fuel: 1) a partial excise tax exemption and 2) income tax credits. (5) Table II-1 traces the history of the federal ethanol tax incentives to date.

As the federal gasoline excise tax has increased to 18.3 cents per gallon, the excise tax exemption on ethanol has also increased somewhat, to 6 cents per gallon before being reduced to the current 5.4 cents per gallon. The key point is that the full exemption, 5.4 cents per gallon, applies to ethanol/gasoline blends which are 10 percent ethanol. Proportionately lower amounts apply to lower ethanol/gasoline blends, 7.7 percent and 5.7 percent blends. In effect, this exemption structure provides a 54 cents per gallon exemption from excise taxes for each gallon of ethanol that is blended with gasoline.

In place of the excise tax exemption discussed above, certain businesses can take one of the following income tax credits:

- (1) A 54 cents per gallon credit for each gallon of blended ethanol.
- (2) The same 54 cents per gallon credit for the sale or use of neat alcohol (neat alcohol is defined as fuel with 85 percent or more alcohol).

In addition, a small ethanol producers credit of 10 cents per gallon for each gallon of ethanol produced up to 15 million is gallons is allowed.

In 1998, Congress voted to extend the ethanol tax incentives until December 31, 2007. The effective amounts of the incentives, however, are to be reduced from the current 54 cents per gallon level to 53 cents in 2001 and 2002, 52 cents in 2004, and 51 cents in 2005 through 2007. The issue of continuance of the incentives is likely to be debated again before the 2007 sunset date.

These federal tax incentives allow ethanol fuel to be sold in the marketplace for 54 cents per gallon less than if these incentives were not in place. By most estimates, this figure amounts to roughly one-half the actual wholesale cost to produce ethanol, allowing ethanol to enter the fuel market at a cost closer to that of gasoline on an energy equivalent basis.

Table II-1: Federal Tax Exemption for Ethanol/Gasoline Blends									
	Prior to 1978	1978-82	1982-84	1984-90	1990-93*	1993-2000	2001-02	2003-04	2005-07
Federal Gasoline Excise Tax (cents/gallon)	4	4	9	9	14	18.3	18.3**	18.3**	18.3**
Excise Tax Exemption for 10% Ethanol Blends (cents/gallon)	--	4	5	6	5.4	5.4	5.3	5.2	5.1
Blender's Income Tax Credit for Ethanol (cents/gallon)	--	--	40 (as of 1980)	60	54	54	53	52	51
<p>* Small producer's credit added in 1990 (10 cents/gallon for first 15 million gallons for qualified small producers with annual output less than 30 million gallons). Excise tax exemption became applicable to 7.7% ethanol blends (currently 4.158 cents/gallon) and 5.7% ethanol blends (currently 3.078 cents/gallon) as of 1992.</p> <p>** Assuming current gasoline tax rate is maintained.</p>									

State Tax Incentives

At least 30 states, including California, have adopted their own ethanol tax incentives at one time or another, with most patterned after and adding to the federal incentives.

Appendix II-A includes a summary of the current ethanol incentives applicable in various states.

From 1981 to 1984, California had a state ethanol incentive in the form of a 3 cents per gallon exemption for 10 percent ethanol/gasoline blends from the state gasoline excise tax, which was then 7 cents per gallon. This excise tax exemption amounted to a 30 cents per gallon incentive for ethanol blended this way. Since the sunset of California's incentive, ethanol/gasoline blends are assessed the full state gasoline excise tax, now 18 cents per gallon.

Neat alcohol fuels are taxed at one-half the prevailing California gasoline excise tax rate. For ethanol in the form of E85, this rate represents about 70 percent of the gasoline excise tax rate on an energy equivalent basis.

How do Federal and State Air Quality Regulations Affect Markets for Ethanol Fuel?

Currently, several federal and state laws currently govern how ethanol may be blended in gasoline in California.

Federal Regulations

The federal Clean Air Act and its several amendments empower the United States Environmental Protection Agency (EPA) to control properties of gasoline, including the oxygen content and fuel vapor pressure. Ethanol and MTBE have been the primary oxygenates used by the oil industry to meet oxygen content requirements established in the Clean Air Act Amendments of 1990.

A waiver granted by EPA under Section 211(f) of the Act in 1978 allowed ethanol to be blended with gasoline at 10 percent by volume and sold commercially. Under the waiver, the resultant "splash blend" of gasoline and ethanol is allowed a higher volatility (vapor pressure) than gasoline alone. To control evaporative emissions from vehicles and fueling facilities, EPA placed limits on the volatility of gasoline in 1989 and again in 1992 in ozone non-attainment areas in the southern states. Ethanol/gasoline blends were exempted from the 7.8 pounds per square inch (psi) Reid Vapor Pressure (RVP) limit, but only for nonfederal RFG areas (federal reformulated gasoline with ethanol does not have an RVP exemption).

In 1990, EPA adopted a wintertime oxygen content rule to combat carbon monoxide (CO) in areas not in attainment with the National Ambient Air Quality Standard for CO. These regulations today apply to all states except California and require a minimum of 2.7 weight percent oxygen for the wintertime months.

In 1995, federal reformulated gasoline (RFG) regulations were implemented for the nine extreme or severe ozone non-attainment regions across the country. Three of these regions are in California, the Los Angeles, Sacramento and San Diego areas. California

reformulated gasoline regulations adopted in 1992 and again in 1996 took precedence over federal RFG. Both these regulations contain fuel volatility controls and oxygen requirements.

California Regulations

California has adopted several regulations to control ozone-forming emissions from gasoline vehicles, gasoline and fueling facilities. While these regulations have generally restricted the practice of “splash” blending of ethanol in finished California gasolines since 1990, a volatility exemption provided for significant use of ethanol in blends with gasoline in the 1980s.

Phase 1 Reformulated Gasoline

This reformulated gasoline was implemented statewide in 1992. The regulation reduced the summertime gasoline volatility to 7.8 psi RVP. Unlike the federal requirement implemented in 1992, the 7.8 psi limit was instituted statewide, not just in ozone non-attainment regions. The regulation did not allow an outright exemption from this requirement for ethanol/gasoline blends. However, 10 percent ethanol blends were not deemed to be in violation of the RVP standard unless the gasoline used in the blend exceeded the RVP standard.

Winter Oxygen Requirement

In response to the federal wintertime oxygen requirement under the Clean Air Act Amendments of 1990, California implemented its program in the winter of 1992. California was allowed to set its own limit on oxygen at 2.0 weight percent based on evidence that NO_x emissions increase at higher oxygen content in California vehicles. Ethanol was used in wintertime gasoline in northern California CO non-attainment regions that year, however, MTBE has become the preferred wintertime oxygenate.

Phase II Reformulated Gasoline

California’s current reformulated gasoline (also referred to as California Cleaner Burning Gasoline -- CBG) was implemented statewide in 1996. This regulation places limits on eight gasoline parameters and composition and is often referred to as a “recipe”. It also further reduced the allowable RVP to 7.0 psi statewide and instituted an oxygen requirement of 2.0 weight percent year around. The oxygen requirement in California RFG is a result of the federal oxygen requirement. Ethanol can be blended into CBG to meet the oxygen requirement and refiners are currently doing so on a small scale (2.0 weight percent oxygen corresponds to 5.7 volume percent ethanol in the gasoline).

This regulation also allows refiners to choose between the “recipe” and a mathematical model, called the “predictive model”. This model gives greater flexibility to the refiners in formulating complying blends of CBG by allowing them to trade off some gasoline parameters for others provided that vehicle emissions (calculated by the model) do not exceed those of the recipe. Under the original predictive model, 2.7 weight percent

oxygen is allowed, corresponding to 7.7 volume percent ethanol, however, the RVP must remain at 7.0 psi maximum. In 1998, the oxygen limit was further increased to 3.5 weight percent when using the predictive model, based on new data. At this level, ethanol can be blended at 10 volume percent, however, RVP must still be maintained at 7.0 psi.

Although California refiners have chosen MTBE as the oxygenate of choice to meet CBG requirements, ethanol is the most likely replacement given the Governor's phaseout of MTBE. Some current blending of ethanol in premium gasoline in the San Francisco Bay and Lake Tahoe areas confirms the ability of refiners to use the predictive model to blend compliant CBG using ethanol.

Phase III Reformulated Gasoline

The California Air Resources Board (CARB) is currently developing California Phase III gasoline regulations. The oxygen requirement could be reduced or eliminated based on data from the Auto/Oil Air Quality Improvement Research Program (6) and CARB's own data. These programs provided evidence that non-oxygenated gasoline conforming to CBG specifications (excepting oxygen) could yield vehicle emissions equivalent to fully complying CBG (containing MTBE). A large vehicle test program in progress will generate new data for an updated predictive model later this year. (7) Variable oxygen content is one of several test parameters.

Under the Governor's Executive Order D-5-99 (Appendix ES-A), California has requested that the federal government rescind the oxygen requirement of the Clean Air Act Amendments of 1990. Even with a zero oxygen requirement, California refiners are expected to blend ethanol to make up for lost volume and octane when MTBE is phased out of gasoline. Under a longer-term scenario modeled for California refiners by an industry consultant, a least cost (to refiners) average oxygen requirement over the course of one year yields a 1 percent (by weight) oxygen requirement. This would amount to about 3.8 volume percent ethanol, on average, in the Phase III gasoline pool for the modeled year 2006. (8)

Fuel Volatility Restrictions

In 1991, the California Legislature and Governor passed legislation that exempted 10 percent ethanol/gasoline blends from the California gasoline volatility restrictions. This legislation contained a clause which would make this blended fuel legal only if CARB determined through testing of a representative group of vehicles using this fuel that emissions did not increase relative to fully complying CBG (with MTBE). In 1998, CARB formally made that determination, that such a blend of ethanol and gasoline increased the ozone forming potential of the combination of evaporative and exhaust emissions. As a result, all ethanol/gasoline blends must comply with the oxygen and RVP requirements of the regulations.

Air Quality Benefit Study

The National Research Council (NRC) recently released a report on the ozone forming potential of reformulated gasoline. (9) This study looked in detail at the role of

oxygenates in improving the performance of reformulated gasoline to reduce ozone. The NRC concluded, *“The use of commonly available oxygenates in RFG has little impact on improving ozone air quality and has some disadvantages”*. The report cited evidence of increases in NO_x emissions with oxygenates in general, but allowed that there were advantages regarding reductions in toxic emissions. The NRC also concluded, *“it appears likely that the use of ethanol containing RFG with an RVP that is 1 psi higher than other RFG blends would be detrimental to air quality in terms of ozone.”*

Ethanol in Flexible Fuel Vehicles

In 1993, California established specifications for E85, a mixture of 85 percent ethanol and 15 percent gasoline for vehicles designed specifically for this fuel. Although not currently available in California, E85 could emerge as a fuel for the future if the economics become more favorable through reduced costs of ethanol production and active marketing by gasoline retailers. Currently, flexible fuel vehicles, designed to use E85 or gasoline in any combination, are being increasingly sold in California. As of the 2000 model year, all of the United States “Big Three” auto manufacturers currently market flexible fuel vehicles such as pickup trucks or vans, resulting in a growing population of “ethanol capable” vehicles.

Global Climate Change and the Role of Biomass-to-Ethanol

Global climate change and specifically, an international concern that anthropogenic activities are causing a warming of the earth’s atmosphere has resulted in several major international meetings in the 1990s to address this concern. While a consensus does not exist in the world scientific community that global warming is a reality today, there is widespread agreement that combustion of fossil fuels in electricity production, buildings, transportation and industrial sectors must be controlled. The principal global warming emissions in the combustion process are carbon dioxide and to a lesser extent methane, two of several important gases known to contribute to the “greenhouse” effect.

International agreements, such as the Protocol to the United Nations Framework Convention on Climate Change signed by many countries including the United States in Kyoto, Japan, in 1997 committed nations to develop country specific carbon reduction goals. The United States committed to reducing global climate change gases 7 percent by 2008 relative to the carbon emissions inventory that existed in the United States in 1990. While the United States has not finalized its strategy to meet these goals, it is expected that a strategy will ultimately emerge and that the Congress will ratify the commitment made in Kyoto.

The transportation sector is the largest single contributor of carbon at 26 percent of total carbon dioxide emissions nationwide. The most recent inventory in California shows that nearly 57 percent of the CO₂ was generated by

transportation sources, more than double that of the nationwide average.(10) Thus, if California is ultimately required under Kyoto Accord commitments passed down by the federal government to reduce CO₂ emissions, then the focus of any State effort at reducing carbon emissions must be on the transportation sector.

Ethanol derived from cellulose has been specifically identified as one potential strategy among others to help meet carbon reduction goals committed to under the Kyoto Accords. (11) Based on analyses performed by Argonne National Laboratory, ethanol in the form of E85 derived from cellulosic biomass can reduce fuel cycle carbon emissions in the range of 80 to 85 percent a per vehicle basis. In its pure form (E100), study results show that ethanol derived from biomass can achieve reductions as high as 100 percent when compared to reformulated gasoline in vehicles. (12) To get this result one has to assume, as Argonne did, no use of energy from fossil fuel sources at any stage of the fuel cycle process.

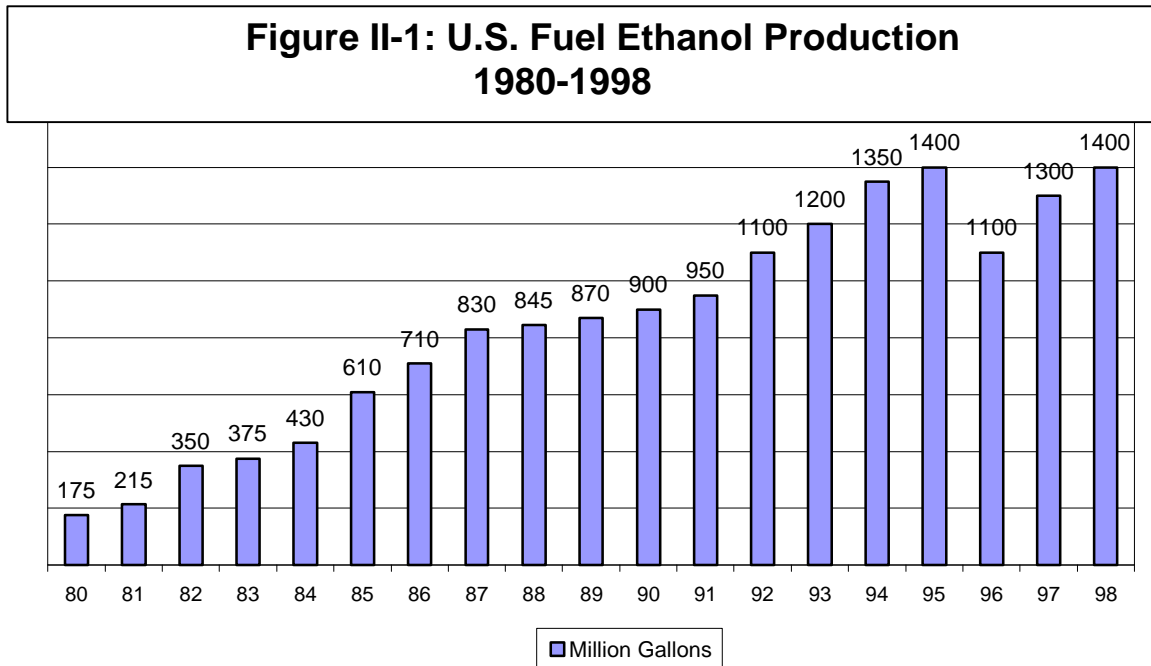
When blended with gasoline, the benefit from ethanol use on a per vehicle basis is reduced significantly because of large dilution effect. Study results show that 7.7 volume percent ethanol in gasoline achieves about an 8 percent reduction in carbon emissions relative to gasoline with MTBE.

This same analysis also shows that corn-based ethanol provides carbon reductions, However, because of fertilizer and fossil fuel use to grow and process corn-to-ethanol, corn based E85 would yield fuel cycle carbon reductions of about 22 percent relative to gasoline. For corn-derived E100, the carbon reduction is about 32 percent relative to the non-recyclable carbon produced with reformulated gasoline. Argonne analysis also shows that ethanol is not the only alcohol capable of achieving large carbon reductions. Methanol (M100) derived from cellulosic biomass can achieve carbon reductions up to 100 percent, just as E100 can.

In summary, the magnitude of potential carbon reductions associated with the use of biomass derived ethanol (or methanol) could be significant in future years. For the year 2010, Argonne calculated carbon reductions attributable to ethanol (as ethanol/gasoline blends in motor vehicles) of 10 percent of all carbon reductions achievable under an efficiency improvement scenario applied across all energy sectors in the United States.

What is the Production Status of Ethanol as a Motor Vehicle Fuel?

As shown in Figure II-1, 1998 U.S. ethanol production tied the previous (1995) record level of 1.4 billion gallons. 1999 production is expected to set a new record. (13) Most of the states with ethanol production plants have some incentive for ethanol production, use or combination of the two. Illinois, Ohio and Minnesota lead the nation in sales of ethanol blends, with each using well over 100 million gallons annually. (14)



Source: Governors' Ethanol Coalition (Lincoln, Nebraska)

Ethanol Production in the Corn Belt States

Nearly all of the ethanol now being used as fuel in the United States is produced from corn feedstock in plants located in the Midwestern corn belt states. Approximately 6 percent of the country's corn crop is presently used to make ethanol. (15) About a dozen plants, with individual capacities of 30 to 200 million gallons per year (gpy), make up 75 percent of the total ethanol industry capacity of about 1.8 billion gpy. These plants are located in Illinois, Iowa, Minnesota, Nebraska, Indiana, Ohio, Tennessee and North Dakota.

Archer Daniels Midland, the largest United States ethanol producer, owns about 43 percent of existing ethanol production capacity in the country. Appendix II-A includes a listing of all existing ethanol production facilities in the U.S.

Ethanol Production in Other States

Ethanol production is beginning in states beyond the corn belt, as at least 19 states are now reporting some ethanol production. Although corn remains the feedstock for most

production, applications of other crops and waste-based feedstocks are increasing. For example, potatoes are the feedstock in Idaho, wheat gluten and cheese whey are used in Minnesota, brewery waste and wood are used in Colorado and Washington, grain sorghum in Nebraska and New Mexico, and various agricultural residues and paper in Wisconsin.

New U.S. Production Capacity

A number of new ethanol production plants (also listed in Appendix II-A) are either under construction or proposed to be built in the U.S. The six projects under construction will add 97 million gpy of new capacity. The 17 proposed projects represent 432 million gpy of new capacity. Three of the proposed projects are in California, and are discussed further in a subsequent section.

Ethanol Imports

Once significant, ethanol imports to the United States have become negligible in recent years due to imposition of a high import tariff on most foreign sources. Brazilian ethanol, the largest potential foreign supply source -- and a past supplier of significant quantities of ethanol to California and other U.S. markets -- is effectively constrained from being imported to the U.S. under the prevailing tariff provisions. Brazil has production capacity for over 5 billion gpy of ethanol.

What is California's Experience with Ethanol Production?

California's experience with ethanol fuel production has included a number of project feasibility studies, a few demonstration projects and several small commercial ventures. Today, one ethanol production facility is operating in the state, a 6 million gpy capacity commercial plant operated by Parallel Products at Rancho Cucamonga in San Bernardino County. This plant, occupying a former winery, uses residues from wine making and other food and beverage industries as its feedstocks. Two other small commercial ethanol plants operated by Golden Cheese Company of California (Corona) and Dairyman's Cooperative Creamery (Tulare), have produced ethanol using cheese whey as feedstock. These plants have a total ethanol capacity of about 3.3 million gpy; however, they are not currently producing ethanol.

Both the California Energy Commission and the California Department of Food and Agriculture (CDFA) have sponsored studies and demonstrations of ethanol production in California. The California Integrated Waste Management Board (CIWMB) has also looked at ethanol production as part of its overall investigations of beneficial applications of various waste materials in the state.

As required by Senate Bill 620 of 1979, the Energy Commission carried out an investigation of alcohol fuels that included both ethanol fuel production feasibility studies

and demonstrations and vehicle fleet demonstrations. (17,18) Seven potential ethanol production projects were examined as part of this program from 1980 to 1983. Table II-2 summarizes the projects studied.

Most of these prospective projects were judged not viable, based on various economic, technical and environmental factors. The estimated ethanol production costs for the first six potential projects listed above ranged from \$1.82 to \$2.36 (1982 dollars) per gallon. Even with the federal and state fuel tax incentives then in place, this range of production costs was considered prohibitively expensive, and none of these projects was pursued beyond the feasibility phase.

Table II-2: Energy Commission Ethanol Production Feasibility Studies (1980-1983)				
Project Name	Location	Capacity	Feedstock(s)	Cogeneration
Tulare Ethanol Production Company	Tulare County	3 Million GPY	Corn, almond hulls, cull fruit	Biomass-fired boiler for process heat
City of Tulare	Tulare County	250,000 GPY	Corn	Biomass-fired boiler for process heat
Adams Alcohol Company	Yolo County	10 Million GPY	Grains	Biomass-fired boiler for process heat & electricity
Golden By-Products	Stanislaus County	2.6 million GPY	Almond hulls	Biomass-fired boiler for process heat
Still Gas , Inc.	San Joaquin County	4.5 million GPY	Corn or sweet sorghum	Biomass-fired boiler for process heat
Joe Garone Farms	Kern County	10 million GPY	Grains & agricultural wastes	Biomass-fired boiler for process heat & electricity
Raven Distillery	Fresno County	8 million GPY	Cull fruit	Natural gas for process heat

The Raven Distillery, the one project selected by the Energy Commission to undertake a demonstration, became the first facility in California to actually produce and market fuel ethanol. This project was located at a pre-existing winery in the town of Selma. The Raven Distillery was projected to have an ethanol production cost of \$1.43 per gallon using cull fruit collected from local fruit packing sheds at no cost. About 150 tons per day of this feedstock, diverted from their normal disposal at the county sanitary landfill, were identified as available. However, this feedstock source was seasonal, requiring other supplemental feedstocks to sustain plant operation during winter months. The seasonal nature of feedstocks had the effect of increasing cost beyond the original estimate, due to the need to purchase supplemental feedstocks, such as waste molasses, which added as much as \$0.36 per gallon to the ethanol production cost.

The Raven Distillery began producing ethanol in October 1981 and continued in operation for approximately an 18-month period. The use of the cull fruit feedstock, besides the seasonal availability limitation, created an odor problem for neighboring residents. This problem, plus the marginal economics of plant operation, especially with the higher cost of using the molasses feedstock, ultimately led to shutdown of the plant. When the Energy Commission's contract for support of the project expired and the operators were unable to fulfill contract repayment terms, the plant equipment was

eventually auctioned off as partial satisfaction of the project's financial obligation to the state.

More recently, in 1997, the Energy Commission collaborated with the National Renewable Energy Laboratory to investigate potential biomass-to-ethanol production in San Joaquin County through the STEP 2 (Sustainable Technology Energy Partnership) Project. The study participants included the University of California, Davis' California Institute of Food and Agricultural Research and Waste Energy Integrated Systems, a private company pursuing an advanced ethanol production process.

The STEP 2 study resulted in preliminary conceptual design data for a biomass ethanol demonstration plant, including a feedstock availability report, bench-scale ethanol production process testing and other process-related research. Four categories of feedstocks were examined, including mixed waste paper, yard waste and agricultural residues, waste wood and food processing waste. (19)

CDFA has also conducted ethanol production feasibility and demonstration programs. One of these programs, the California Alcohol Fuel Plant Design Competition, resulted in 17 submitted designs for farm-scale ethanol production facilities using various agricultural feedstocks. Three finalist projects were constructed and their performance was monitored. The winning design, the Gildred/Butterfield Fuel Ethanol Plant near Paso Robles, received a \$50,000 award in exchange for a report detailing the specifications, construction, operation and performance of the facility. (20) The plant, with an estimated production capacity of about 70,000 gallons per year, operated for a period of time in the early 1980s using barley, wheat and other agricultural feedstocks.

CDFA also conducted an Energy and Chemical Feedstock Crop Demonstration Program to examine the potential for production of fuels, chemicals and other petroleum substitute products from California crops. This program, initiated in 1990, undertook demonstrations with four crops -- sweet sorghum, kenaf, canola and lupine. The results of these demonstrations are discussed further in Chapter IV, which examines energy crop potential.

CIWMB recently undertook a feasibility study of alternative methods of utilizing various types of agricultural and forestry residues, including application as feedstock for ethanol production. The resulting report outlines the potential for producing ethanol from different types of residual materials, while also identifying a number of other commercial applications for such products. (21) The report generally describes a bright future for beneficial commercial applications of these types of wastes and residues that will reduce the need for traditional disposal practices. Energy applications, including ethanol production, are seen as candidates among a variety of other promising uses, all subject to similar identified constraints, including economics, environmental concerns, manufacturing issues and markets for end products.

Other organizations have also conducted investigations of the feasibility of various biomass-to-ethanol concepts applicable in California. A recent example is a study

sponsored by the National Renewable Energy Laboratory examining both stand-alone and collocated ethanol/electricity production facilities designed to use forest residue feedstocks. Process designs, heat and material balances, process flow diagrams, and capital and operating costs were developed for 20 million gpy facilities assumed to be located at Martell in Amador County, the site of an existing biomass electric power plant. (22)

Proposed Ethanol Projects in California

In the 1990s, California has witnessed renewed interest in ethanol production, with several new biomass-to-ethanol projects in the planning and development stages. These proposed projects, with production capacities ranging from 4 to 20 million gpy of ethanol, all intend to use some type of waste or residue feedstocks and employ advanced production processes to produce ethanol, electricity and other coproducts. None of these projects, each described briefly below, is yet firmly committed to begin construction or assured of being realized.

BC International, Gridley Ethanol Project

BC International Corporation, of Dedham, Massachusetts, is pursuing development of a biomass-to-ethanol facility near Oroville, in Butte County. The Corporation has a proprietary patented processing technology for producing ethanol. The Gridley plant, located in the center of the state's rice-growing region, intends to use rice straw as its primary feedstock. The traditional practice of burning rice straw is being phased out under California legislation, creating interest in alternative applications for this residue, including ethanol production. Wood residues from area orchards, forests and mills would provide supplemental feedstocks for this 20 million gpy capacity plant. The proposed plant site is adjacent to an existing biomass electric power plant, offering the potential to combine electricity generation and ethanol production from the same biomass feedstocks. BC International Corporation's first project of this type is under development at a former petroleum refinery and grain-to-ethanol plant site at Jennings, Louisiana, where sugar cane residues will be the feedstock. BC International Corporation is completing the financing arrangements for the Jennings project, expected to cost \$90 million and require 18 months for retrofitting the existing plant.

The Gridley project would be this BC International's second commercial ethanol venture, following the Jennings project. Both the Energy Commission and the U.S. Department of Energy have provided early funding support to develop the Gridley project, of which the City of Gridley would be a major partner and operator.

BC International, Collins Pine Ethanol Project

BCI and the Collins Companies, a timber firm, are planning another biomass-to-ethanol plant at an existing biomass electric power plant site at Chester, in Plumas County. A study team has completed a feasibility study of this proposed 20 million gpy capacity facility, which would use forest thinnings and wood wastes as feedstock. (23) The team was headed by the Quincy Library Group, with participants including the Energy Commission, National Renewable Energy Laboratory, California Institute of Food and Agricultural Research, the Plumas Corporation and TSS Consultants.

The Quincy Library Group is a forum for California environmental organizations, county officials and timber industry groups seeking solutions to the accumulation of excess woody material in the Plumas and Lassen National Forests as a result of continued forest fire suppression. Ethanol production is seen as one attractive option for beneficial application of the forest material that needs to be harvested to lessen the potential for catastrophic wild fires and other related forest health problems. The Energy Commission and U.S. Department of Energy have provided early funding support for this project.

Sacramento Ethanol Partners, Arkenol Ethanol Project

Arkenol Inc., of Mission Viejo, is the project developer for a proposed plant near Sacramento that would use rice straw and wood wastes as feedstocks for various products, including 4 million gpy of ethanol production capacity. The primary product currently planned to be produced by this facility is citric acid. Arkenol, affiliated with ARK Energy, an electric power plant developer, has patented ethanol production process technology it is seeking to employ in a number of ethanol plant projects in the U. S. and other countries.

The Sacramento area project was initially planned as a joint project with the Sacramento Municipal Utility District (SMUD), and called for construction of a natural gas-fired electricity cogeneration plant on the same site. However, SMUD is no longer an active participant, and the project is undergoing redesign. The U.S. Department of Energy is providing funding support for this project.

What is Ethanol's Role in California's MTBE Phaseout?

The potential role of ethanol as an alternative gasoline oxygenate component in California has been under active investigation. The Energy Commission's study of MTBE alternatives, which helped lay the groundwork for the Governor's Executive Order intended to phase out MTBE, describe a major potential role for ethanol as an MTBE replacement. (8)

Evaluating Substitutes for MTBE

The establishment of realistic potential to replace MTBE – considering the availability of practicable substitutes, including ethanol – has had a major bearing on the state's decision to proceed with an expeditious (i.e., 3-year) phaseout schedule. Water quality and health-related issues clearly formed the primary impetus for the phaseout decision, including key University of California study findings that MTBE poses an environmental threat to groundwater and drinking water. (24) Nevertheless, the existence of viable replacement options is fundamental to the success of the phaseout, and the contribution of ethanol stands to be an important factor.

The Energy Commission's MTBE Alternatives Study examined four different oxygenates listed as approved gasoline additives by the U.S. Environmental Protection Agency (EPA). These are: tertiary butyl alcohol (TBA); ethyl tertiary butyl ether (ETBE); tertiary

amyl methyl ether (TAME); and ethanol. All four of these options were also judged to have desirable gasoline blending properties and to offer adequate supply availability, although other factors – including acceptability from an environmental standpoint – were not examined as part of this study. Three MTBE phaseout time frames were considered: immediate, intermediate-term (three years), and long-term (six years).

Energy Commission MTBE Alternatives Study – Findings Regarding Ethanol

Among the MTBE Alternatives Study's findings addressing ethanol, particularly those pertinent to the three-year phaseout schedule selected by the Governor's Executive Order, were:

- Maximum reliance on ethanol as a replacement for MTBE equates with a need for as much as 1.15 billion gpy of ethanol by 2002. In addition, up to 2.18 billion gpy of new gasoline supply would be needed, because a lower percentage blend of ethanol (6 percent) was assumed to replace the higher percentage (11 percent) of MTBE used.
- The higher fuel volatility resulting from ethanol/gasoline blending must be offset by substituting certain gasoline components in order to meet California's gasoline specifications.
- Sufficient volumes of ethanol are believed to be available to meet this level of new California demand, although the impact on gasoline cost – estimated at 6.1 to 6.7 cents per gallon – would be the highest of any of the alternative oxygenate cases studied. A much lower cost impact (1.9 to 2.5 cents per gallon) was estimated for use of ethanol as a longer-term MTBE replacement.
- Most of the ethanol that would be used in California in an intermediate (three-year) MTBE phase-out would be imported from other parts of the U.S.
- Potential California sources of ethanol will not be a likely contributor to supply within a three-year MTBE phase-out, although some 46 million gpy (now estimated to be 44 million gpy of planned capacity, plus 6 million gpy of existing capacity) of in-state ethanol production capacity was noted to be in planning stages.
- New California ethanol production sources that could eventually help supply this demand would benefit from a transportation cost advantage of 10 cents per gallon or more over out-of-state sources.
- Certain unique handling requirements for ethanol would necessitate investments in California's gasoline distribution infrastructure, expected to require 18 to 24 months to complete and to add about 0.1 cent per gallon to gasoline cost.
- A modest fuel economy penalty due to ethanol's lower energy content is estimated to add about 1 cent per gallon to gasoline cost.

Range of Ethanol Demand for Use in California Gasoline

Besides the above estimate from the Energy Commission's MTBE Alternatives Study of a maximum potential demand for up to 1.15 billion gallons per year, other studies have also developed estimates of California's prospective demand for ethanol as a gasoline blending component. Three of these studies were used to develop a range of ethanol demand estimates for gasoline blending in the state. (25,26,27) These estimates employed a variety of assumptions regarding factors that will affect ethanol demand, including whether a federal oxygenate requirement continues to apply, use of ethanol for octane enhancement, and acceptable ethanol blending percentages.

The resulting range of estimates compiled from these studies (presented in detail in Appendix II-B) is from 148 million to 1.034 billion gallons of ethanol per year by the end of the MTBE phaseout period. Note that the upper end of this range approaches (within about 10 percent) the maximum demand estimated by the Energy Commission MTBE Alternatives Study. Using the MTBE Alternatives Study's maximum estimate of 1.15 billion gallons per year as the upper figure, the estimated range of ethanol demand for ethanol/gasoline blending represents from a low of 1 percent to as much as 8 percent (by volume) of California's current highway gasoline market.

Of course, it should be noted that the other prospective markets described earlier for ethanol besides ethanol/gasoline blending could contribute to higher future ethanol demand estimates, representing greater potential shares of the state's overall transportation fuel market of over 22 billion gallons per year.

Related California Studies of Ethanol

The Governor's Executive Order acknowledges the potential role for ethanol as an oxygenate replacement for MTBE and directs state agencies to further explore the prospects for ethanol production and use in the California. Along with this study of the potential for an in-state biomass-to-ethanol industry, two other studies are underway that will bear on the future of ethanol/gasoline blending in the state.

CARB and the State Water Resources Control Board are conducting an environmental fate and transport analysis of ethanol in air, surface water and groundwater. This study will help determine, among other things, whether ethanol used as a gasoline oxygenate does in fact offer an effective solution to the types of water contamination problems associated with MTBE use.

The Office of Environmental Health Hazard Assessment is preparing a related analysis of the health risks of ethanol in gasoline, including the products of incomplete combustion and any resulting secondary transformation products. Together, the findings of these studies, along with resolution of the outstanding regulatory issues affecting oxygenated gasoline and ethanol gasoline blending, will establish a clearer outlook for ethanol as part of California's motor fuel supply and demand picture.

What Are California's Near- and Long-term Ethanol Supply Options?

If California becomes a major growing market for ethanol fuel, potential sources of supply include new in-state production facilities, existing and new production facilities elsewhere in the U.S., and foreign sources.

California in the Overall Ethanol Supply Picture

Any serious consideration of a California state government initiative to foster an in-state biomass-to-ethanol fuel industry must take into account not only the market prospects for this fuel but also the outlook for other potential sources that California-produced ethanol would likely compete with. Most of the remainder of this report is devoted to inventorying the resource potential of various candidate ethanol feedstocks in California, estimating resulting ethanol production potential, and examining the processes, economics and development issues associated with such an industry in the state. New multi-faceted "biorefinery" facilities that would produce ethanol as part of various waste-to-energy problem solving strategies are highlighted. Approaches that would involve cultivated energy crop feedstocks are also looked at. Evaluating the attractiveness and viability of any of these different routes to a California ethanol supply industry requires placing them in the proper context of the overall national and international ethanol supply picture.

Existing Midwest U.S. corn-based supply sources appear to be the likely near- and intermediate-term candidates for supplying any California market for ethanol/gasoline blends emerging from the scheduled phase-out of MTBE. Meanwhile, as shown in Appendix II-A, new ethanol supply projects using corn and other crop feedstocks, as well as some using waste-based feedstocks, are planned in an increasing number of other states. California's current in-state proposals for ethanol production amount to a small increment of this planned U.S. capacity expansion.

Brazil, and perhaps some other ethanol-producing countries, could conceivably supply ethanol to California and other U.S. markets, as in the past. However, Brazilian supply and most other foreign sources, while potentially offering excess supply availability – and competitive prices -- are currently disadvantaged by the U.S. ethanol import tariff, which effectively offsets the federal ethanol tax incentives on ethanol fuel.

In the longer-term, a growing market demand for ethanol fuel in California could see competing supply sources among in-state waste-based or energy crop-based production, expanded production from traditional corn-based or waste-based production elsewhere in the U.S., or foreign sources. Synthetic ethanol production processes, using natural gas or other hydrocarbon feedstocks, are also being applied and represent a somewhat unknown factor as competitors with biomass-based production.

What Factors Will Determine the Most Competitive Sources of Ethanol?

As with other domestic and international industries, the outlook with respect to which ethanol supply sources will ultimately prove most competitive in the California marketplace rests among a variety of circumstances, some perhaps within California's control, others not. Some of the important factors likely to affect future competition among these different sources include:

- Continuation of the U.S. government's favorable treatment of ethanol from domestic biomass-based sources, thus keeping foreign sources and synthetic production at a competitive disadvantage.
- The advent of possible new California state government policies and actions that favor in-state ethanol production with subsidies or other forms of support or protection.
- Progress with ethanol process technology advancements that reduce the cost and/or increase the efficiencies of using certain types of feedstocks (i.e., wastes and residues) over others.
- Trends in feedstock cost reduction, including incorporating the value of avoided waste disposal and/or reflecting other currently non-monetized benefits of applying waste or residual feedstocks. Also, market trends in competing beneficial applications of feedstocks.
- Transportation costs from ethanol production locations to ethanol markets and the advent of improved, lower cost technology for ethanol transportation and distribution (e.g., pipelines).
- Market demand factors that affect the relative marketability of ethanol in or near the producing regions versus in more distant markets.
- Fuel quality requirements and the ability of various ethanol process technologies and feedstocks to conform with these requirements.
- Regional differences in the availability, cost and marketability of other transportation energy alternatives.

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CHAPTER III

WASTE BIOMASS RESOURCES IN CALIFORNIA

III. Waste Biomass Resources in California

Introduction

This chapter defines and describes biomass, waste biomass and residues identified as candidates for ethanol production. In addition, estimates of the physical resource potential in California for various waste and residual biomass categories are discussed. The economic, environmental factors and challenges, including competing markets and disposal options, affecting the viability of ethanol production are also examined.

Utilizing the fermentation process, ethanol can be produced from three main sources:

- Sugar, including sugar cane and sugar beets
- Starch, including grains like corn and wheat
- Cellulose, including trees, paper waste, agricultural residues, etc.

This section will focus on the latter category, often generically referred to as biomass.

What is Waste Biomass?

Biomass is a broad term, generally defined as matter produced through photosynthesis, consisting of plant materials and agricultural, industrial, and municipal wastes and residues derived therefrom.(1) Biomass is often referred to as *cellulosic* or *lignocellulosic biomass* to differentiate it from grain-based, starch-containing feedstocks and sugars, which are also forms of biomass. The term is also descriptive, as biomass contains three primary constituents: cellulose, hemicellulose and lignin, and can contain varying amounts of other compounds (i.e., extractives).

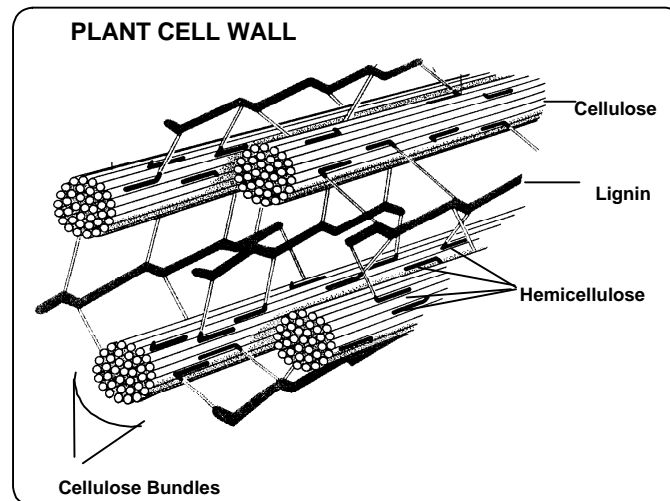
Cellulosic biomass must be highly processed to make available sugars that can be fermented into ethanol, compared to sugars (requiring the least processing) and starches. The extensive processing required for cellulosic materials is more costly than that for processing starches and sugars. Cellulosic materials are also unique to starch- and sugar-based feedstocks in that they are inherently low energy-density fuels, which means that they are comparatively expensive to collect, process and transport. The important advantages of cellulosic residues are their relative abundance and potentially low, or even negative, cost.

Waste biomass can be considered unwanted products or materials having no further value or use. However, many of the biomass resources discussed in this section are not truly wastes but rather residues. The majority of forest and agricultural materials produced are utilized in one way or another, maintaining some value, and do not end up in municipal solid waste landfills.(2)

Various forms of cellulosic biomass outwardly appear to be very different; however, their chemical makeup is quite similar. About 35 percent to 50 percent of the material is cellulose –containing the six-carbon sugar glucose. Another 15 percent to 30 percent is hemicellulose -- generally dominated by the five-carbon sugar xylose. The remaining 20 percent to 30 percent is composed primarily of lignin, with lesser amounts of extractives, ash and other components.(3) (See Appendix III-A for additional material)

Both cellulose and hemicellulose are carbohydrates that can be broken down (hydrolyzed) by enzymes, acids or other compounds to simple sugars. Lignin cannot economically be converted to ethanol, but may be used as a high-energy-content boiler fuel for electric power generation and other applications. Potentially, lignin also can be used as a feedstock for chemical synthesis to produce a variety of products, including phenols, aromatics, olefins, surfactants and adhesives.(4, 5)

Figure III-1 (6)



As Figure III-1 shows, the cellulose and hemicellulose are contained in bundle-like structures, with lignin acting like glue to bond the bundles together. The process of converting lignocellulosic biomass to ethanol involves pretreating the biomass to separate the carbohydrate fraction and breaking down these bundles

to access the available sugars. The various means of hydrolysis and fermentation are discussed in Chapter V and its appendix.

It should be noted that various technologies can be applied to biomass for the production of products other than ethanol. Other transportation fuels, for example, that can be derived from biomass include methane, methanol, hydrogen and Fischer-Tropsch fuels (synthetic fuels that can be used in place of gasoline or diesel).

What Types of Waste and Residual Biomass Resources Exist in California?

California has substantial waste and residual biomass resources because of its rich agricultural and forestry resources and its large volume of commercial and municipal solid waste materials. Resources reviewed in this section comprise the following major categories:

- Agricultural residues
- Forest/chaparral residues
- Municipal solid waste

In addition, out of state biomass sources and other potential sources of biomass are briefly discussed. Collectively, California's estimated gross biomass resource potential for waste and residue sources that are convertible to ethanol totals approximately 50.7 million bone dry tons (bdt). This amount does not include energy crops or out of state resources, which could add significantly to this total.

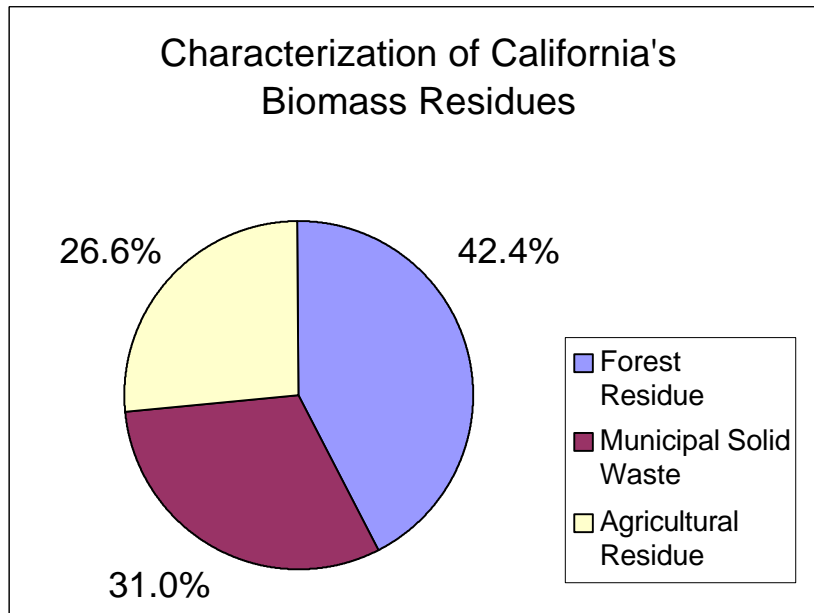
The gross amount of biomass (waste and residue resources) will vary from year to year. Some resource categories can be expected to increase, while others will likely decrease. Based on limited staff analysis, California's long-term trend for the amount of biomass generated should remain relatively flat. This will be discussed in greater detail in the sections that follow.

The gross biomass resources discussed in this chapter include portions that are currently being used, those that do not have markets at present, as well as materials that may be considered uneconomic or problematic to convert to ethanol. For example, the biomass power industry consumes approximately 5 million bone dry tons of assorted wood waste, agricultural residues, and other feedstocks.⁽⁷⁾ Consequently, the amount that realistically could be used today as ethanol feedstock is considerably less than what is physically available. Because of the numerous factors that impact cellulosic feedstock viability (collection costs, conversion yields, changing market conditions and other factors) and the limited

scope of this study, no attempt has been made in this chapter to characterize waste and residual feedstock costs. Additional discussions on this follow in chapters VI and VII.

The characterization of gross waste biomass resources in the state is illustrated in Figure III-2 and displayed in Table III-1. Table III-1 shows the estimated waste biomass residues produced annually in California in million bone dry tons. For comparison, estimates include figures from the Energy Commission's *1991 Biomass Resource Assessment Report for California* (See Appendix III-A for additional material).

Figure III-2



**Table III-1
Breakdown of
California's
Biomass
Residues**

Waste/Residual Biomass Resource Category	Million BDT CEC Biomass Report, 1992*	Million BDT (Revised)	Percent of Total (Revised)
Paper (landfill)	NA	8.7	17.2%
Field and Seed Crops	6.6	7.9	15.6%
Chaparral	7.7	<u>7.7</u>	15.1%
Lumber Mill Waste	5.5	<u>5.5</u>	10.8%
Forest Slash	5.2	4.5	8.9%
Forest Thinnings	1.6	3.8	7.4%
Urban Wood Waste	1.6	3.2	6.4%
Fruit and Nut Crops	1.9	3.0	6.0%
Urban Yard Waste	3.1	2.9	5.7%
Food Processing Waste	1.7	<u>1.7</u>	3.4%
Other [#]	0.9	<u>0.9</u>	1.9%
Vegetable Crops	0.9	0.9	1.7%
Total	36.7	50.7	100%

*California Energy Commission, *Draft 1991 Biomass Resource Assessment Report for California*, December 1992

[#]'Other' category includes small quantities from various sources, such as nursery crop residue.

Underlined is the same for both revised and original Energy Commission study of 1992.

Agricultural Residues

California has long been the leading agricultural producer in the nation. According to the *1998 California Agricultural Resource Directory*, gross income from agricultural production in 1997 reached \$26.8 billion (including dairy, livestock and poultry). California's agricultural sector is considered one of the most diversified in the world, with no one crop dominating the state's farm economy. Some 350 different crops are grown in the state; consequently, residues from this sector are substantial.(8)

Currently, much of the residue from California agriculture is incorporated into the soil or used for other purposes. Rice straw and orchard prunings, however, appear to be the principal agricultural residues that are strong candidates for ethanol conversion.

The overall acreage devoted to agriculture in California is decreasing slightly over time, a trend that is expected to continue for the foreseeable future. Much of this land is being converted to commercial and residential uses. At the same time, a shift to higher value crops including grape vines, and fruit and nut trees is occurring. Crops such as corn and wheat are expected to decrease over time as water costs and other factors make these crops less attractive to grow in the state.(9)

At present, large amounts of rice straw and prunings are burned. While some of the orchard prunings are burned in fields, much is also an important feedstock for the biomass power industry in the production of electricity. Some other residues, such as wheat straw, are also now being considered for use as ethanol feedstock material.

Field and Seed Crop Residues

Field and seed crop residues included in this study are from barley, bean, oat, rice, rye, wheat, corn, cotton and sorghum. The biomass residues from field and seed crops are the materials that remain in the ground after harvesting.(10) In the Midwestern US, research is underway to utilize corn stover (corn cobs, stalks and leaves) to produce ethanol. California's corn crop produces about 2.7 million bone dry tons of stover. It is rice straw, however, that has attracted great interest in the state for ethanol use. The state's stringent air quality regulations and public pressure is stimulating the search for viable alternatives to burning rice straw, making it an attractive candidate for ethanol production.

Rice Straw

Rice straw is plentiful in the Sacramento Valley, where approximately 450,000 acres are devoted annually to rice production.(11) Traditional means of disposal

is open field burning, an environmental liability because of the significant amount of undesirable air emissions generated (especially particulates). Resulting legislation (Assembly Bill 1378, 1991) mandates a reduction in the amount of straw which may be open burned.(12) While more recent legislation has relaxed the time schedule for phasing down open burning (Senate Bill 318, 1997), rice straw continues to be considered a viable ethanol feedstock. At the time of this writing, two projects are being developed to utilize rice straw and other feedstocks for ethanol production; these projects are highlighted in Chapter II.

Total available rice straw in the state is approximately 1.5 million bone dry tons annually. (13) Through Senate Bill 38 (1996), the California Legislature has established the Rice Straw Utilization Tax Credit Program. The tax credit of \$15/ton of rice straw goes to the end user for any purpose, such as manufacturing, production of energy, etc. (excluding burning). The program is limited to \$400,000 a year and is distributed on a first come/first serve basis. The tax credit annually represents 26,667 tons of rice straw, or about 9,000 to 13,000 acres. The program sunsets on January 1, 2008 and is administered by the California Department of Food and Agriculture.

Senate Bill 318 also created the Rice Straw Demonstration Project Fund, which is directed by the California Air Resources Board (CARB). The Fund's goal is to help create a market for Sacramento Valley rice straw by providing cost-sharing grants for projects which show the best potential for commercial and sustainable uses of rice straw. A total of \$2.25 million was utilized during the 1998/99 fiscal year. In addition, this same legislation requires CARB to develop an implementation plan to find uses for 50 percent of the rice straw by the year 2000. This challenging program deadline is not expected to be met. Approximately 13,500 tons of rice straw are currently utilized off field (about one percent of the total straw produced annually).(14) Additional information on these programs can be found in Appendix III-B.

Suitability

Residues from several field and seed crops are well suited to ethanol conversion. While rice straw is the feedstock in this category that is being pursued the most at present, it is not particularly suitable conversion material. Compared to other forms of lignocellulosic biomass, rice straw has a high ash content, resulting in lower ethanol yields.(15) Overall suitability depends on such factors as consistency of supply, feedstock quality (i.e., free from contaminants), and cost of collection and transport.

Competing Uses

The majority of the residues from field and seed crops are incorporated back into the soil after harvest.(16) By doing so, organic matter and nutrients are returned to the soil. The soil's ability to hold water and resist erosion is enhanced.

Although a significant amount of rice straw is incorporated into the soil, there is concern that continuous soil incorporation could lead to higher incidence of plant disease. Developing viable alternatives to open burning or soil incorporation is critical.(17)

Alternative uses of rice straw also include cattle feed, paper pulp, fiberboard products, straw housing material, animal bedding, livestock feed, erosion control, citric acid and power generation.(18) Current off-field alternative uses of rice straw comprise only about 2% of the estimated straw generated annually.

Challenges

Challenges to the use of rice straw for ethanol include the following:

- Difficulty of collecting residues in wet fields
- Limited availability of and high cost of equipment for harvesting and handling
- Lack of demonstrated history converting rice straw to ethanol
- Seasonality of feedstock
- Potential for other, more economical disposal alternative uses (e.g., soil incorporation, construction materials, etc.)

Fruit and Nut Crop Residues

The fruit and nut crop residues included in this study are prunings or brush from almond, apple, apricot, avocado, cherry, date, fig, grapefruit, grape, kiwi, lemon, lime, olive, orange, peach, pear, pistachio, plum, prune and walnut trees. Clearing orchards of old or diseased trees is another source of residue. Total residue from fruit and nut crops is about 3 million bdt/year. In addition to orchard prunings and whole trees, cull fruits (fruits that are damaged or of inferior quality) offer another feedstock opportunity for ethanol.

Suitability

Biomass residues from fruit and nut crops appear to be attractive for ethanol conversion. If the feedstock is relatively free from contaminants, such as dirt, prunings can be a viable ethanol feedstock. Cull fruits contain high levels of sugar and make for relatively easy conversion to ethanol. However, process technologies that are designed to treat cellulosic feedstocks may not be well suited for processing fruits because of the fundamental differences in the feedstock compositions. Also, the availability of cull fruits will vary widely and is heavily dependent on weather and crop conditions.

Competing Uses

Much of this resource is either disposed of through open field burning or has use in other industries. In 1989, approximately 39 percent of the residues were open field burned.

In 1990, 330,000 bone dry tons of fruit and nut crop residues were consumed in biomass power plants. However, because the biomass power industry is using less prunings today, more of this resource could be available for ethanol production. A small portion of the wood produced from fruit and nut trees is also sold as firewood.(19) Some cull fruit is used for sugar production or other food products. Therefore, its availability as an ethanol feedstock appears limited.

Challenges

Challenges to using this category for ethanol feedstock include the following:

- The residue can be contaminated from soil, especially if the material is left in fields for a long period of time.
- Like many other agricultural crops, they are seasonal in nature, mainly available from November to March.
- Potentially wet or muddy fields may restrict collection.
- Removing a large portion of the residues from the fields/orchards would impact soil quality.
- The economics of collecting, chipping and transporting this biomass resource may be costly, making much of it uneconomic.

Vegetable Crop Residues

Vegetable crops included in this report include artichoke, asparagus, cucumber, lettuce, melon, potato, squash and tomato. Total residue from vegetable crops is approximately 860,000 bdt/year. A sizable portion of this resource is incorporated back into the soil. To collect this residue for ethanol use, farmers would have to find it more economically attractive than tilling it back into the soil. Vegetable crop soil incorporation is useful for nutrient replacement, water retention and erosion control. Given the limited amount of this resource, its value to enrich the soil and its wide geographic distribution, vegetable crop residues do not appear to be strong candidates for conversion to ethanol.

Forest Residues

Forest residues are being considered for conversion to ethanol because of the substantial amount of biomass potentially available and because conversion is seen as a partial means of improving forest health. Residues from the forest include branches and small trees left after logging operations, as well as trees collected from thinning operations.

Forestry experts have repeatedly stated that a dangerous situation has developed in forests from decades of fire suppression and other traditional management practices.(20) To prevent forests from burning, fire suppression efforts have caused overgrowth in forests as large numbers of small trees and shrubs increased the density of vegetation and the species mix. Ironically, this in turn has led to increased risk of catastrophic wildfires, which differ substantially from natural fires (i.e., fires from lightning). High intensity fires result, destroying virtually everything in their wake and incinerating the top layer of duff and soil. Furthermore, overstocking of California's forests diminishes wildlife habitat quality and may increase disease in overcrowded tree stands.(21)

To prevent overloading in the forests, mechanical thinning operations and prescribed burning, a common practice of periodic controlled burnings of forest areas can be used to reduce the risks of catastrophic fires. The forest residues generated from thinning and logging have little value for timber or paper products and must be disposed of through burning or other means. Conversion of forest residues to ethanol and/or electricity, with coproducts offers an attractive alternative to burning. (See Appendix III-A for additional material)

According to the California Department of Forestry and Fire Protection, the state's timber industry yields about \$1 billion annually. Of the state's approximately 40 million acres of forestland, some 13 million acres is commercial timberland that would likely benefit from thinning.(22) The primary trees in this forest environment include Ponderosa Pine, Sugar Pine, Fir, Douglas Fir, Incense Cedar and Redwood.

The United States Forest Service manages approximately one-half of the forestland in the state. At least 250,000 acres per year of the land under US Forest Service jurisdiction would benefit from thinning operations. Through thinning efforts, benefits can be realized in improved forest health, lowered catastrophic wildfire risks and other related areas. (23)

Forest residues generated will likely increase before stabilizing. Attempts are being made to increase mechanical thinning of forests to reduce wildfire risks. Additionally, as California's population continues to rise, residential and commercial development will push further into existing wildland areas. This is expected to increase property values in those areas and provide greater incentive to remove fuels that may otherwise present a fire hazard.(24)

Forest Slash

Forest slash or logging residues are the portions of the trees that remain on the forest floor or at the site after logging operations have taken place. This material consists mostly of tree branches, tops of trunks, stumps, branches and leaves.

Forest Thinnings

As mentioned earlier, thinning operations are mainly intended to reduce the density of tree stands, thereby reducing the risk of catastrophic wildfires.

Thinning materials are generally not of sufficient quality to be utilized for lumber. The amount of forest thinnings available will likely be higher in the early

years of a major forest thinning campaign. Over the long-term the amount of thinnings available from California forests will be lower than in the early years.

Lumber Mill Waste

Lumber mill wastes or lumber processing residues consist of the slabs, shavings, trimmings, sawdust, bark end pieces of wood, and log cores that result from the various processing operations occurring in sawmills, pulpmills, and veneer and plywood plants. (25)

Suitability

Forest residues are desirable because of their large and relatively uniform supply. Lumber mill waste, however, has a high percentage of bark, which is not well suited for ethanol conversion. As mentioned above, because much interest has been generated in thinning activities to improve long-term forest health and reduce the potential for catastrophic fires, motivated parties may be willing to pay for removal of unwanted forest vegetation. These parties include government forestry agencies and private land owners. Depending on the cost to accomplish this, forest residue conversion may be attractive.

Competing Uses

Nearly one third of the forest slash that is collected is consumed by the power industry in California (1990 figure). Nearly all of the mill waste is currently utilized in existing markets, incorporated into a variety of wood-based products. These markets include electricity, paper, firewood, composted material, particleboard, and other building materials.(26) For residues to be diverted for ethanol use, the purchaser must be willing to pay more than its value in competing markets.

Challenges

Challenges to using forest residues for ethanol feedstock include:

- In environmentally sensitive areas and endangered species habitats, logging has often been limited or banned.
- Forests are often geographically remote, where roadway infrastructure may be inadequate or non-existent.
- Many wildland areas are on steep slopes that make residue removal difficult or impossible.
- Collecting, chipping and transporting forest residue is costly and will likely need to be subsidized to compete with other feedstocks (by land owners, fire suppression agencies, etc.).

- The availability of equipment to collect and handle forest residues is limited.
- Some specialized vehicles used in forest residue removal are restricted from using public highways, making it difficult to collect and transport this material.(27)

Chaparral Residue

Chaparral consists of heavily branched dwarf shrubs of various species that grow mainly in arid locations in southern California.(28) If not removed, chaparral will eventually become a major fuel source for wildfires in California. Chaparral is now, and is expected to continue to be, thinned periodically to minimize fire risk. This is often accomplished by conservation corps or fire protection agency personnel. Although little commercial use is made of chaparral, the brush lands surrounding many of Southern California's foothill communities could be a source of biomass for ethanol production.

Chaparral in Southern California is comprised of several species. These include: Chemise, Ceanothus, Scrub Oak, and others.(29) California has approximately eight million acres of chaparral, equating to 7.7 million bone dry tons of potential material that could be utilized.

Suitability

Chaparral appears to be an unlikely feedstock candidate for ethanol production. Besides being difficult, and therefore costly to harvest, ethanol conversion yields are generally low. These species tend to be high in extractives and lignin, and low in cellulose and hemicellulose. Also, air emissions and water effluents are expected to be higher than other biomass feedstocks.(30) Large subsidies would likely be needed to overcome the high cost of collecting and transporting this resource. Furthermore, low ethanol yields are expected from chaparral residues.

Competing Uses

No competing uses appear to be employed for chaparral.

Challenges

Challenges to using chaparral for ethanol feedstock include:

- High cost of collecting and transporting the material
- Much of the available chaparral is found on steep slopes, making it difficult or impossible to collect
- Potentially high air emissions and water effluents
- Low ethanol conversion yields

Municipal Solid Waste

In 1998, California disposed of approximately 37.5 million wet tons of solid waste in landfills (and diverted more than 33 percent of its waste).(31) Table III-2 shows the composition of California's municipal solid waste stream.(32)

Table III-2

Commercial/Industrial Waste Stream		Residential Waste Stream	
Paper	43%	Organics	43%
Organics	30%	Paper	31%
Plastics	10%	Plastics	7%
Metal	7%	Other	6%
Glass	4%	Glass	5%
Construction & Demolition	3%	Metal	4%
Other	3%	Construction & Demolition	4%
TOTAL	100%	TOTAL	100%

Source: California Integrated Waste Management Board.

Areas in **bold** are potential ethanol feedstocks

Municipal solid waste (MSW) streams that can be potentially diverted for ethanol production include the following:

- paper waste (e.g., newspapers and magazines)
- urban wood waste (part of “construction” category that includes pallets, construction material and wood processing waste)
- urban yard waste – or green waste (part of “organics” category, includes grass clippings, etc.)
- and other organic materials.

The motivating factors to convert MSW to ethanol include legislative directives to reduce landfill material, the potential to collect sizable tipping fees (a charge levied by refuse collection sites, which can help offset conversion costs), significant year-round resource availability, and the benefit of having a centralized collection and processing site. Much of the needed infrastructure for collection, transport and handling of waste streams exists within the current waste disposal system in California.

Facilities that process MSW, separating recyclable material, compost material, etc., may be attractive sites to collocate with an ethanol production unit. Where tipping fees are sufficiently high, and collection and processing well integrated, the economics may be compelling enough to develop such a waste-processing/fuel-production plant. Integration in this case would include recycling, waste treatment, resource conversion (especially cellulose) to marketed products and disposing of process wastes.

In Orange County, New York, the Masada Corporation is developing a facility to process MSW and sludge that will produce ethanol as one of its products. Within

the state, projects such as the STEP-2 project in the San Joaquin Valley (see Chapter II) have also investigated converting MSW to ethanol.

Limited staff analysis did not reveal a clear trend as to whether California's MSW stream – that portion that can be captured as ethanol feedstock – will increase, remain relatively constant or decrease. Factors affecting this trend include the expected increase in the state's population, the effectiveness of reducing waste streams and the development of markets for waste resources.

Urban Yard Waste

Grass clippings, leaves, tree and bush trimmings from both residential and commercial properties make up urban yard waste. The CIWMB's most recent estimate (1990) is 6.4 million tons (about 2.9 million bone dry tons) of yard waste generated in the state.

Suitability

Urban yard waste appears to be a viable feedstock candidate as long as there is a uniform and clean waste stream.

Competing Uses

A large portion of urban yard waste is incorporated into the soil or is used for compost material. In addition, some urban yard waste is incinerated or disposed of by open field burning.

Challenges

Challenges to using urban yard waste for ethanol feedstock include:

- Contamination of yard waste (dirt, garbage, rocks, etc.)
- Seasonal changes in availability
- Potential technical difficulties in the conversion process
- Does not store well because of high decomposition rate

Urban Wood Waste

Urban wood waste primarily includes shipping pallets, construction and demolition debris, whole trees and tree pruning residues.

Suitability

Urban wood waste appears to be an attractive feedstock for ethanol and is an important feedstock for the biomass power industry.

Competing Uses

Unlike many other waste biomass sources, urban wood waste has existing markets. These markets include electricity, particleboard, compost, and others. As mentioned earlier, the biomass power industry is moving toward a deregulated electricity market. As subsidies are reduced, more biomass power plants may close, making additional supplies of wood waste potentially available for ethanol production.

Challenges

Challenges to using urban wood waste for ethanol feedstock include:

- Possible contamination of wood (chemically treated woods, nails, etc.)
- Large variability of wood type and quality
- Competing uses as described above
- Inconsistent availability

Paper Waste

One of California's largest available resources is mixed waste paper. Approximately 14 million tons were generated in 1997. Of this total, approximately 9.5 million tons (8.7 bone dry tons) were disposed of in landfills, with the remainder reused through various recycling processes.(33) The relative attractiveness of this waste resource is dependent on several variables. These variables include the paper waste fraction at a particular material recovery facility, the type of paper material available, the quality of material, and other factors. Where waste streams are adequately separated, whether up front by the consumer or at the plant, paper waste and other feedstocks can be collected for processing to ethanol with relative ease.

Suitability

Although the mixed waste paper resources in the state are substantial, it is unclear how viable this resource is for ethanol production because of contamination and other issues.

Competing Uses

Paper residues that are currently sent to landfills are of generally low grade material and have little market value. Some mixed paper waste is utilized in electric power production, while some may also be used in pulp manufacturing.

Challenges

Challenges to using paper waste for ethanol feedstock include:

- The difficulty of converting certain paper types (i.e., high gloss papers contain compounds that may make conversion difficult) (34)
- Papers that are contaminated or contain inks can cause difficulties in the conversion process, depending on the process (concentrated acid hydrolysis appears to be fairly tolerant of contaminated paper)
- Potential cost of separating clean paper waste
- Competing use markets that exist, as well as potential markets that may develop as efforts are made to find alternatives to landfill disposal
- Regulatory barriers that may discourage the conversion of MSW to ethanol (i.e., AB 939 that limits the credit to “transform” waste rather than recycle, etc.)

Other Waste Biomass Sources

Other California Sources

Other sources of waste biomass feedstock also exist, but have not been included in the gross biomass resource potential (Table III-1) because of their generally low conversion yields to ethanol or other factors that make their viability marginal at best. Livestock manure is such an example. The Energy Commission’s past work in assessing biomass resources for the power industry concluded that approximately 11.9 million bone dry tons exist in the state (1992). However, the carbohydrate fraction of manure is low, resulting in poor conversion yields and rendering it comparatively uneconomic for this application. Further, the high moisture content and chemical makeup of manure may present additional and potentially costly steps in the conversion process. Manure appears to be better suited to other energy conversion processes, including anaerobic digestion for methane gas production. However, additional investigation should be pursued before consideration of manure for ethanol is completely ruled out.

Out of State Resources

Beyond the state’s own domestic resources, it is possible that biomass could be imported from outside the state and converted to ethanol. While this scenario seems unlikely at the present, it deserves mention. The most likely resource would be forest material coming from the Pacific Northwest and, to a lesser degree, portions of Western Nevada.

Oregon’s forests, for instance, cover about 28 million of the state’s 62 million-acre land base. Approximately 65,000 Oregonians work in sawmills, plywood plants,

pulp and paper manufacturing operations, logging and trucking companies, and wood furniture manufacturing facilities.(35) Residues from logging, forest thinning and sawmills are substantial. Furthermore, Oregon faces similar forest health problems as Northern California, as evidenced by this statement from the Oregon Department of Forestry:

It's estimated that 25 percent of Oregon's forests are either dead or dying from insects, disease and prolonged drought. That's almost 7 million acres of forests, most of that is located in central and northeast Oregon. ...the combined effect of the dead and dying trees and exclusion of fire have resulted in an unprecedented accumulation of fuel and the potential for unstoppable catastrophic wildfires. The state believes that a careful but intensive forest management approach is needed, especially on federal lands which have been particularly hard hit. Long-term actions should include thinning of stands to improve tree spacing and providing a healthy and diverse mix of tree species that are tolerant to drought, insects and fire.(36)

Oregon's substantial forests provide the potential for a waste residue stream that could be utilized in areas near the California/Oregon border.

The suitability, competing uses and challenges for out of state biomass resources are essentially the same as those highlighted in the forest residue section. The principal difference appears to be the expected higher costs due to transporting distances and possible restrictions for interstate commerce.

Federal Action to Promote Use of Biomass

President Clinton, on August 12, 1999, signed an executive order entitled "Developing and Promoting Biobased Products and Bioenergy." The stated intent of this Executive Order is "to stimulate the creation and early adoption of technologies needed to make biobased products and bioenergy cost-competitive in large national and international markets." In a separate Executive Memorandum, the President also directed the Secretaries of Energy and Agriculture to prepare a report outlining options for modifying federal programs toward a goal of tripling national use of biobased products and bioenergy by 2010. (See Appendix III-C for more information.)

Other features of the President's Executive Order include:

- Declares the Administration's policy to develop a comprehensive national strategy, including research, development, and private sector incentives to carry out the above-stated intent.

- Establishes an Interagency Council on Biobased Products and Bioenergy composed of the Secretaries of Agriculture, Commerce, Energy and Interior, the Administrator of the US-EPA, and other members. This council is charged with preparing an annual strategic plan for pursuit of national objectives involving biobased products and bioenergy.
- Creates an Advisory Committee on Biobased Products and Bioenergy, with up to 20 members appointed by the Secretary of Energy, to provide information and advice to the above Interagency Council.
- Directs the Departments of Agriculture and Energy to establish working groups on biobased products and biobased activities.
- Establishes a National Biobased Products and Bioenergy Coordination Office to ensure coordination of the above multi-agency federal activities and support the work of the Interagency Council.

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CHAPTER IV

BIOMASS CROP RESOURCE POTENTIAL IN CALIFORNIA

IV. Biomass Crop Resource Potential in California

Introduction

This chapter examines the potential for producing ethanol in California from biomass energy crops. It identifies different types of crops that are candidate feedstocks for ethanol production, reviews previous studies of the potential for energy crop-based ethanol production in the state, and discusses key factors that affect the prospects for realizing this potential.

Why Consider Energy Crops for Ethanol Production?

Most of the recent focus on new biomass-to-ethanol production potential in California centers around the types of waste- and residue-based feedstock sources covered in the previous chapter. The waste disposal and environmental issues associated with these types of feedstocks, and the benefits attributable to energy applications of such materials, make them the leading feedstock candidates for biomass-to-ethanol projects being proposed for the near-term.

Biomass energy crops, cultivated, harvested and supplied directly for their energy value, represent the more conventional approach to supplying feedstocks for ethanol production. Virtually all world ethanol production today relies on crops such as sugar cane and corn. Furthermore, any prospects for supplying a major fraction of transportation energy needs with biomass-derived fuels require consideration of the potential of energy crops, including new and improved varieties selected and cultivated specifically for energy production.

Most appraisals of the longer-term, larger-scale potential for ethanol as an alternative fuel view cultivated energy crops as the ultimate feedstocks, after the more limited resource opportunities for waste and residual feedstocks are captured. One such appraisal, by Lynd et al, concludes: "although it is widely agreed that waste feedstocks will be utilized before energy crops, the fact that large-scale displacement of conventional transportation fuels with cellulose ethanol will require significant production from dedicated energy crops is equally apparent." (1) Once the costs of obtaining supplies of suitable waste and residual feedstocks reach a certain level -- suggested by Lynd in the study cited above to be about \$45/bdt -- economics could begin to favor crop feedstocks.

Furthermore, advanced ethanol production process technologies currently under development have application to many crop-based as well as waste-based feedstocks. This raises possibilities for future ethanol producing facilities capable of accommodating feedstocks from both types of sources.

What Types of Energy Crops Can Be Used to Make Ethanol?

Two general categories of energy crops could be adapted to producing ethanol -- multi-purpose crops that have other agricultural markets and “dedicated” energy crops, selected and cultivated solely for energy production. Multi-purpose crops, such as the familiar examples of corn in the U.S. and sugar cane in Brazil, represent almost all of the world’s ethanol production to date. The future outlook for ethanol production from energy crops is more concentrated on crops selected specifically for and dedicated primarily to this purpose, including those most adaptable to advanced cellulose conversion processes.

Despite its standing as the top agricultural-producing state in the U.S., California has yet to be extensively studied for its potential for growing energy crops to produce ethanol fuel. The California Department of Food and Agriculture (CDFA) has conducted limited investigations of this potential, with some additional research in this area undertaken by the University of California, Davis and others. Nationally, the U.S. Departments of Energy and Agriculture have sponsored evaluations of energy crop potential, including ongoing studies at Oak Ridge National Laboratory. Continuing research and limited applications of energy crop technologies internationally provide further information to help examine the prospects for crop-based approaches to supplying ethanol.

Table IV-1 is a listing of energy crop candidates identified in the literature, divided into four categories: annual field crops, perennial grasses, woody perennials, and aquaculture crops. The suitability of individual crops for different energy applications varies, with direct combustion for heat or electricity generation, extraction of vegetable oil fuels, and conversion to ethanol comprising the major options. The geographical and climatic adaptability of these various energy crops also varies from region to region. Thus, only selected crops will be optimally suitable for cultivation in any candidate growing region. Resource requirements, including the necessary land acreage and water supply, further affect the applicability of individual energy crops to particular regions. Table IV-1 highlights a number of potential energy crops that have been investigated, at least preliminarily, for California application, though not necessarily for ethanol production.

To date, specific energy crops best suited for cultivation for ethanol production in California have not been definitively studied. However, CDFA has done limited studies of a few of the energy crops listed in Table IV-1. These include field crops such as sweet sorghum, perennial grasses such as elephant grass and tree crops such as eucalyptus. Certain types of crops have generally been

discounted from serious consideration for California energy crop application. Corn, for example, although currently the source of most U.S. ethanol production, is not generally considered economically viable to grow as an ethanol feedstock in California due to irrigation water requirements. A 1981 feasibility study for a large corn-based ethanol plant at Benicia included a feedstock plan that involved importing corn from the Midwest U.S. (2)

Table IV-1: Candidate Energy Crops

FIELD CROPS		
Rape Seed	Soy Bean	Spring barley
Rye	Sunflower	Hemp
Sugar beet	Triticale	Cardoon
Miscanthus	Kenaf	Jerusalem artichoke
Sweet sorghum	Buchina	Broom
False flax	Corn cockle	White mustard
Knotweed	Spartina	Cuphea
Potato	Prickly pear	Guar
Sweet Potato	Corn or maize	Pearl millet
Flax	Buffalo gourd	Sugar cane
Amaranth	Grindelia	Rice
Fodder beet	Meadowfoam	Wild Tobacco
Lupine	Wheat	Alfalfa
Sericia lespedeza		
PERENNIAL GRASSES		
Switchgrass	Intermediate wheatgrass	Orchard grass
Reed canary grass	Napier grass	Bermuda grass
Sudan grass	Elephant grass	
WOODY PERENNIALS		
Eucalyptus	Poplar	Willow
Alder	Birch	Sycamore
Tumbleweed	Cottonwood	Silver maple
Black Locust	Sweetgum	Casuarina
AQUACULTURE CROPS		
Kelp	Water hyacinth	Cattail
Algae	Reed	

Bold entries are crops that have been investigated for California

Aquaculture crops are another relatively little-studied category of energy crops of potential interest in California. The energy potential of certain types of aquatic crops grown in wetlands, lakes, bays and oceans may offer particular opportunities for the state, given its extensive aquatic access and temperate climate. Aquaculture energy crop candidates that have received at least limited research attention include species of algae and kelp, and plants such as water hyacinth and cattail, some of which are believed to offer higher rates of

production than land-based crops. However, specific aquaculture crops considered highly suitable for ethanol production have yet to be developed.

What Is the Extent of Energy Crop Potential in California?

As the nation's top-producing agricultural state, California clearly has the potential to produce energy crops as part of its broad slate of agricultural products, currently estimated to include over 350 different crop varieties. Nevertheless, California has thus far not been seriously considered in national studies of energy crop production potential, due to general assumptions that water requirements and other environmental and economic factors favor other regions for growing energy crops.

CDFA's various assessments over the years, however, have concluded that opportunities do indeed exist to develop crop-based ethanol production in California as part of the state's overall agricultural industry. According to CDFA, dedicated energy crop plantations could provide for in-state fuel production while providing a means to diversify agricultural markets, help stabilize the agricultural economy and contribute to rural economic development. Among the specific candidate energy crops identified by CDFA are sweet sorghum, kenaf, Jerusalem artichoke, buffalo gourd, industrial potatoes, fodder beets, elephant grass, switchgrass, sericea lespedeza, eucalyptus, poplar, and casuarina. (3)

Estimating the physical potential for crop-based ethanol production in California depends on the acreages assumed to be devoted to this purpose, the choices of energy crops and their projected yields, and the expected productivity of the ethanol process. One benchmark for crop-based ethanol production is provided by today's U.S. corn-to-ethanol industry, which typically produces about 270 gallons of ethanol per acre of corn. At the upper bound, potential ethanol yields from certain dedicated energy crops are estimated to be as high as 1,000 gallons per acre.

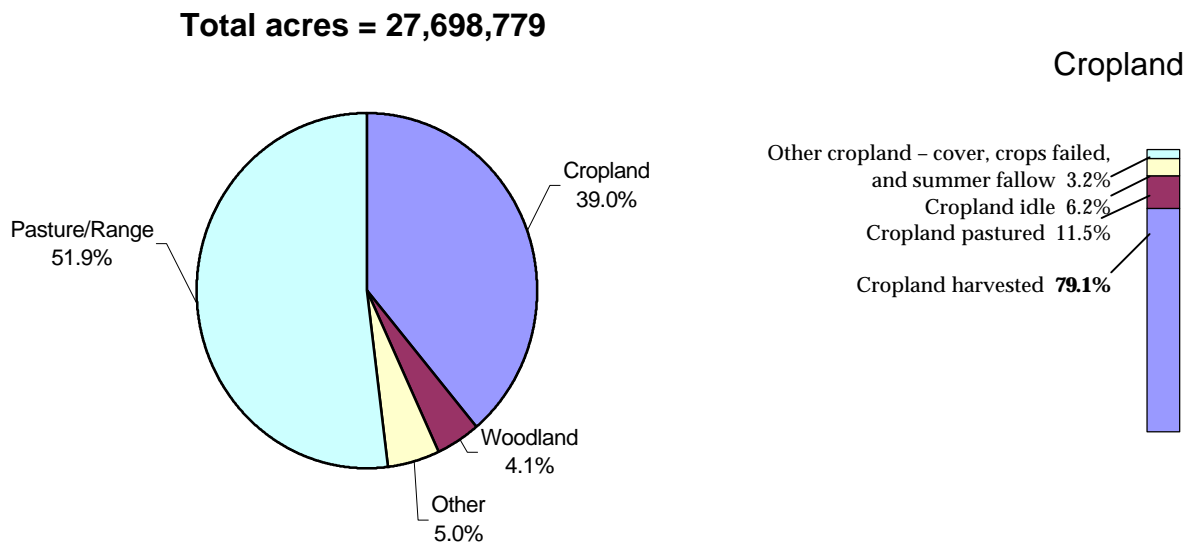
Figure IV-1 shows the existing distribution of California's 28 million acres of agricultural lands, which comprise roughly one-fourth of the state's total land area. Pasture and range lands account for over one-half this agricultural land acreage, with cropland comprising 39 percent. Forest lands, both productive and unproductive, comprise about 40 percent of California's land area, desert lands about 24 percent, and urban areas only about 5 percent.(4)

While no reliable estimates have been developed of the ultimate potential for energy crop development in the state, CDFA has provided limited estimates of ethanol production potential based on simply adapting small fractions of this in-use agricultural acreage. Devoting 10 percent of the current 10 million acres of the cropland fraction of agricultural lands to production of energy crops such as

sweet sorghum, fodder beets or industrial potatoes would support production of an estimated 500 million gallons of ethanol per year. This estimate assumes 500 gallons of annual ethanol production per acre of energy crop, about the midpoint of the above range of existing and potential crop-based ethanol yields.

Larger estimates of ethanol production potential would result from expanding the analysis to include use of agricultural lands not currently applied to crop production as well as additional land not presently devoted to agriculture. The above CDFA estimate suggests that each 1 million acres of crop production, occupying roughly one percent of the state's total land area, would supply the ethanol equivalent of about 3 percent of California's current gasoline demand.

Figure IV-1: California Agricultural Land Use -- 1997



1997 CENSUS OF AGRICULTURE

The potential for aquaculture crop production may also be substantial. A 1979 study sponsored by the Electric Power Research Institute estimated the maximum potential energy yield of marine biomass from U.S. coastal waters at about 30 quads.(5) This compares with today's use of energy in the U.S.

transportation sector of about 25 quads.(6) California coastal waters accounted for about 20 percent of the total resource estimate. The report identified various marine aquatic species considered suitable for conversion to energy products, including liquid fuels such as ethanol. The study also noted that processing of aquatic materials could consume a large fraction of the energy available from the harvested biomass.

Are There Any Previous Studies of Ethanol Production from Energy Crops?

California Department of Food and Agriculture Investigations

CDFA has investigated ethanol production from some selected potential California energy crops in more detail as part of its Energy and Chemical Feedstock Crop Demonstration Program initiated in 1990. (7) This program included a series of field demonstrations and laboratory studies involving a variety of identified energy crops. Two of these, sweet sorghum and kenaf, were found to have desirable characteristics for potential crop-based ethanol production in California. The CDFA program's findings for these two crops are summarized as follow:

Sweet Sorghum

Demonstration plantations of sweet sorghum varieties were grown in 1990, 1991 and 1992 by twelve different farmers in eight California counties, ranging from the southern San Joaquin County, to the central coast, to the northern Sacramento Valley, to the high plains of Lassen County. Yields ranged from 1.6 to 13.5 bdt/acre, with an average of 7.6 bdt/acre. Total costs of production up to harvest ranged from \$32 to \$90/bdt, with irrigation cost accounting for from \$44 to \$100/acre, or about 15 per cent of total production cost.

Evaluation of both ethanol-only production and ethanol/electricity coproduction scenarios yielded the following energy potential estimates for this crop: ethanol production only – 145 to 1,228 gal/acre (690 avg.); coproduction – 72 to 658 gal/acre (355 avg.) ethanol and 884 to 7,109 Kwh/acre (4,100 avg.) electricity. Inputs of required production energy were viewed as favorable, with fertilizer and herbicide inputs also reportedly low and pesticide input zero. About one-half the irrigation water requirements of corn under similar conditions was reported.

Kenaf

This crop was studied as a candidate for cultivation in California's cotton growing regions. With yields up to 11 bdt/acre, kenaf was determined to be more expensive to produce than sweet sorghum. Kenaf has a variety of non-

energy markets with higher values, with applications ranging from carpet backing to poultry litter. A scenario of secondary ethanol production from kenaf reclaimed from its original use as poultry litter showed a feedstock cost of \$15/bdt and an ethanol production potential of 34 gal/ton, resulting in a feedstock cost of \$0.44/gal without coproduct credit.

The program's conclusions noted that these crops are agronomically and technically feasible. However, several factors were noted that must be addressed before these and other energy and industrial crops are to become economically feasible: (1) continued agricultural development to assure higher and more consistent yields; (2) development of more resource-efficient biomass production systems; (3) further development of post-harvest systems; and (4) public policy that assures pricing of energy sources to include externalities including environmental impacts and impacts to local, state and national economies.

University of California, Davis Studies

Researchers at the University of California, Davis (UCD) have, for a number of years, studied various energy crops for application in California, including crops suitable for ethanol production.(8) Corn, sweet sorghum, sugar beet and fodder beet are among the crops investigated in UCD field experiments. This work added further confirmation that sweet sorghum, in particular, has favorable characteristics as an ethanol feedstock crop. Sweet sorghum was shown to produce about 23% more fermentable carbohydrates than corn, while requiring only 37 percent as much fertilizer and 17 percent less irrigation water. Annual ethanol yields from sweet sorghum were reported at 475 to 575 gallons per acre.(9)

Other Studies

Other U.S. studies have examined the potential for producing ethanol from tree crops such as eucalyptus and poplar. One non-site-specific analysis considered poplar as the feedstock for a large-scale ethanol production facility employing advanced processing technology.(10)

This study of a large hypothetical facility, comparable in size to the largest existing corn-to-ethanol plant – with a capacity of more than 300 million gpy – considers the ethanol production potential from poplar feedstock produced from a land area within a 50 mile radius, corresponding to the maximum transport distance for a typical corn-based plant. In this case, (optimistic) assumptions of 10 tons of harvested feedstock per acre per year and 100 gallons of ethanol production per ton of feedstock result in an estimated production potential of 5

billion gpy that could hypothetically be supported by such a 5 million acre plantation.

The U.S. Department of Energy's Oak Ridge National Laboratory, as part of its Bioenergy Feedstock Development Program, conducts analyses of energy crop potential in the U.S., including regional applicability of specific energy crops.(11) Over 125 tree and nonwoody crop species have been screened as potential energy crops by this program; participants include 30 universities, 5 U.S. Department of Agriculture research units, and 4 private companies.

The program employs a model to identify U.S. locations where favorable conditions for energy crop production exist. Poplar has been identified as an attractive energy crop candidate for the Pacific Northwest, and the program is sponsoring several studies related to poplar cultivation in this region. Other regional program activities involving both tree crops and perennial grasses are ongoing in the South Central and Southeast regions, the Northeast region, and the North Central region of the country.

Internationally, development of various energy crops is ongoing in many other countries. The recent Fourth Biomass Conference of the Americas, held in Oakland, California in August/September 1999, featured at least 40 papers dealing with biomass crops by presenters from 17 different countries.(12) More than 20 different energy crops were included among the topics of the research presented in these papers, covering all aspects of crop propagation, harvesting, handling and processing.

What Are the Factors Affecting Crop-Based Ethanol Development?

While crop-based ethanol production may offer more ultimate long-term resource potential, the future of this approach in California is, in some ways, subject to more uncertainty than that of waste- and residue-based approaches. Even though crop-based sources represent virtually all current world ethanol production and will most likely supply any near-term markets for ethanol in the state, no plans are in evidence for production of ethanol from California-grown energy crops. Planned expansion of the U.S. corn-to-ethanol industry is unlikely to extend to California, and the only active proposals to develop new ethanol production capacity in the state are the planned waste-based projects described in an earlier section.

Some aspects of crop-based ethanol production likely to have an effect on whether or not this course proves viable for future application in California are briefly discussed as follow:

Economics

Feedstock costs are a key driver of overall ethanol fuel economics, prompting a heavy focus on ethanol production approaches estimated to have low-cost or no-cost feedstock sources -- usually waste- or residue-based approaches. Thus, the ability of crop-based ethanol feedstock candidates to achieve feedstock costs competitive with waste- and residue-based sources will be an important determinant of the viability of crop-based production. Some progress appears to be being made in this respect. Meanwhile, competing markets for residual feedstocks, and increasing costs of acquiring adequate waste feedstock supplies may serve to improve the competitiveness of crop-based feedstocks. Improvements in ethanol production process economics may represent a neutral factor between waste- or residue-based and crop-based feedstocks but could improve the overall market picture for ethanol and thus accelerate the need to expand supply beyond that available from waste or residual feedstocks. Trends in agricultural economics, including government policies to continue or add support for energy produced from the farming sector, will also play a role.

Land Use

Dedication of significant areas of usable land to any form of energy production always raises a difficult issue, more so when agricultural acreage is at stake. Use of waste and residual feedstocks for ethanol production has an obvious advantage in this respect, since no significant new land use requirements are usually involved. Any proposals for growing new energy crops for ethanol production are likely to reopen traditional “food versus fuel” arguments that waste-based approaches avoid. Nevertheless, modern agriculture exhibits increasing overall productivity, as well as the ability to produce a multiplicity of food, energy and other products, as well-illustrated by the U.S. corn-to-ethanol industry. An increased public understanding of the benefits of integrating energy production with agricultural production could serve to dispel the traditional food versus fuel controversy and allow more serious consideration of crop-based ethanol options. Such options may prove particularly attractive where they can be effectively applied on marginally productive or set-aside lands.

Irrigation Water

Water supply for agricultural irrigation is a sensitive issue in California, especially where new water rights or expanded usage for new acreage or crops is

involved. Waste and residual feedstocks, as well as crop-based feedstocks grown in other regions with adequate precipitation, seem to have a clear advantage in this regard to potential crop-based ethanol feedstocks grown in California that require expensive and difficult to obtain irrigation water. Still, the advent of drought-tolerant low water-requiring energy crops suggests the potential to at least partly overcome this constraint, as would development of suitable aquaculture energy crops. Furthermore, some current California crops with high water requirements that face diminishing markets or declining market values might be partially replaceable with energy crops with a net decrease in water application. Certain types of energy crops may also have the potential to employ low-quality water sources or wastewater, and even contribute to removal of contaminants from polluted water resources.

Environmental Impacts

Various environmental impacts that have come to be associated with conventional agriculture – soil erosion, pesticide and fertilizer runoff, air pollution, etc. – are general impediments to any new or expanded farming practice, energy crops included. However, compared with most existing farming practices, cultivation of certain energy crops may offer considerably reduced environmental impacts. Reduced fertilizer requirements and reduced or eliminated pesticide application are two important characteristics noted for some crops, such as sweet sorghum, that have been studied as potential ethanol feedstocks in California. Some energy crops, either as replacements for or rotated with conventional crops, may also offer soil enhancement and erosion control benefits and improved wildlife habitat.

Global Climate Change

Ethanol fuel may offer one of the most promising options for reducing the transportation sector's contributions to atmospheric carbon dioxide greenhouse gas build-up. If global climate change mitigation becomes an increasing societal priority, both the extent of ethanol production and use and the selection of ethanol feedstocks and production processes could be affected. Evaluations of fuel cycle carbon emission characteristics have revealed significant differences among various current and prospective means of producing ethanol, ranging from minimal carbon-reducing benefit to near total elimination of net carbon release. Thus the selection of ethanol fuel cycle, including feedstock, processing technology and types of energy inputs to the cycle, can be a major determinant of the resulting greenhouse gas implications, with certain crop-based cycles potentially yielding the best effect. Also, relying on ethanol fuel as a substantial part of a global warming solution would equate with development of the larger resource potential of crop-based feedstocks.

Market Demand

Interwoven with several of the above factors is the overall outlook for ethanol fuel demand, as affected by ethanol's own progress as an alternative fuel, but also by cost and supply trends of other competing conventional and alternative fuels. Should any combination of prevailing factors serve to create sustained growth of an ethanol fuel market beyond near-term requirements for replacing MTBE, crop-based production will ultimately be needed to meet this demand.

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CHAPTER V

BIOMASS CONVERSION PROCESSES

V. Biomass Conversion Processes

Introduction

This chapter describes the most competitive current technologies and probable improvements to increase the rate of conversion, yields and efficiency of production of ethanol, electricity, and coproducts from urban, agricultural, and forest wastes, and from energy crops. These improvements are expected to result in lower costs per gallon of ethanol produced in 2003 and beyond.

This chapter surveys various technologies for converting biomass to ethanol, including the more established approaches, research on methods to improve them, and possible features of a mature biorefining industry. (See Appendix V-A for more details on all of these topics.)

Background

Large-scale production costs for biomass-based products depend primarily on the delivered cost of the raw material and on the costs of the conversion processes.

Biomass conversion industries could potentially become cost-competitive with petroleum-based industries if research, development, and demonstrations significantly reduce processing costs.(1) Major improvements leading to cost reductions seem most likely in two areas: the chemical pretreatment of biomass wastes and the biological conversion of these wastes.

A biorefinery may be the most economical approach to converting biomass to ethanol because other products from the biomass such as electricity, process steam, and chemical coproducts lower the cost of producing ethanol. This approach could lead to an integrated biomass industry that is environmentally and economically sustainable.

For example, hemicelluloses in waste biomass can be converted into ethanol. Celluloses can be converted into additional ethanol or into chemicals, pulp or fibers. Lignin can serve as a high-energy fuel for electricity and steam production. Extractives can produce a wide variety of commodity and high-value chemicals.

What Are the Steps to Convert Biomass to Ethanol?

This chapter outlines the processes used to convert biomass to ethanol. Both this chapter and the supporting Appendix E utilize historical and current technical information provided by the National Renewable Energy Laboratory (NREL) in its 1999 Bioethanol Strategic Roadmap.(2)

In a typical biomass conversion to ethanol, the biomass might undergo the following:

Pretreatment Step

First, the wastes are pretreated. Pretreatment makes the biomass structure more accessible to the subsequent steps.

The biomass is reduced in size by cutting and milling. It may also be washed. It is then subjected to physical, chemical, or biological pretreatment, or to a combination of these.(3)

Chemical pretreatments to make the biomass more digestible have received the most research; these pretreatments utilize dilute acids, alkalines, organic solvent, ammonia, sulfur dioxide, carbon dioxide, or other chemicals.

Hydrolysis Step

In concentrated acid hydrolysis, the cellulose and hemicellulose are converted to sugars with concentrated sulfuric acid and diluted with water at modest temperatures.

Dilute acid hydrolysis is both the oldest technology for facilitating conversion of biomass to ethanol and also the approach that has received the most research and commercial interest.

Enzymatic hydrolysis is the most recent of these methods and the one that depends most on biological developments.

Planned Projects Using Hydrolysis to Convert Biomass to Ethanol and Other Products

Two facilities plan to use concentrated acid hydrolysis to convert biomass to ethanol. For the Sacramento Ethanol Partners Project near Sacramento, Arkenol plans to use rice straw to produce citric acid and ethanol and to recover amorphous silica from the rice straw. The Masada Resource Group in Orange County, New York, plans to use municipal solid waste and sludge to produce ethanol, lignin and gypsum.

BC International and the Department of Energy, Office of Fuel Development, have formed a cost-shared partnership to develop a 20 million gallons per year biomass-to-ethanol plant in Jennings, Louisiana using dilute acid hydrolysis to recover sugar from bagasse (sugar cane wastes) and rice hulls. A proprietary, genetically-engineered organism will ferment the sugars from bagasse and rice hulls to ethanol.

BC International also presently plans to use two-stage dilute sulfuric acid technology with rice straw and wood wastes as the feedstocks in the Gridley biomass-to-ethanol facility to be collocated with the Pacific Oroville Power Plant. If enzymatic hydrolysis (discussed later in this chapter) proves reliable and cost-

effective, then one-stage of dilute acid pretreatment followed by enzymatic hydrolysis will be considered as an alternative.

The proposed BC International Collins Pine plant at Chester, California, would also be collocated with an electric power plant. The plan is to pretreat the softwood feedstocks with dilute sulfuric acid, followed by enzymatic hydrolysis and fermentation of sugars to ethanol using proprietary bacterial enzymes. The softwood extractives will be converted to two or three chemical coproducts: the beginnings of a California forest waste biorefinery.

Tembec and Georgia Pacific operate sulfite pulp mills that use dilute acid hydrolysis to dissolve hemicellulose and lignin from wood and produce specialty cellulose pulp. The hexose sugars in the spent sulfite stream are fermented to ethanol. The lignin is either burned to produce process steam or converted to value-added products such as dispersing agents or animal feed binders.

Fermentation Step

In the fermentation step, sugars are converted into ethanol. This production step may be performed separately or combined with enzymatic hydrolysis.

Hydrolysis Combined with Fermentation

Enzymatic hydrolysis combined with fermentation converts pretreated biomass into sugars by one of several methods described in Appendix V-A.

Interest in enzymatic hydrolysis of cellulose began in the South Pacific during World War II, when an organism now called *Trichoderma reesei* destroyed cotton clothing and tents. The U.S. Army laboratory at Natick, Massachusetts set out to understand the action of this fungus and to harness it. They found that the fungus produces enzymes now called “cellulases” because of their effectiveness in hydrolyzing cellulose. Subsequent generations of cellulases have been developed with increased effectiveness great enough to achieve commercial applications.

Petro-Canada signed an agreement in 1997 with Iogen Corporation to co-fund development of a biomass-to-ethanol technology based on Iogen’s proprietary cellulase technology, and with the aid of the Canadian government, to begin construction of a demonstration plant in 1999. As previously mentioned, BC International will begin operation of their plant in Jennings, LA using dilute acid hydrolysis technology, but they will allow for the utilization of enzymatic hydrolysis when cellulase production becomes cost-effective for their facility.

Cellulase production (for enzymatic hydrolysis) and ethanol production in a single reactor vessel by a single microbial community is known as consolidated bioprocessing, or as direct microbial conversion (DMC). If the required technological advances can be achieved through genetic engineering followed by cost reductions through improved practice, then consolidated bioprocessing in a form suitable for a biorefinery could serve as a model for what might be achieved long-term in a California biomass-to-ethanol industry.

Gasification Followed by Fermentation

In gasification-fermentation, the biomass is first gasified, converting the biomass into a mixture of smaller molecules that includes carbon monoxide, carbon dioxide and hydrogen. The molecules are then reassembled into ethanol by fast fermentation processes.

Bioengineering Resources, Inc has developed a technology that combines gasification followed by fermentation to produce ethanol from a variety of biomass wastes. Plans are underway to test this technology in a pilot project as a step toward commercialization. The yields can be high (a figure of 136 gallons of ethanol per ton of feedstock is projected) because all of the major biomass fractions, hemicellulose, cellulose, *and* lignin, can be converted to ethanol.

What Are the Methods for Grain- or Sugar-Based Ethanol Production?

This section summarizes the processes used to convert grains and sugars into ethanol. These processes are used by the Midwest ethanol industry, which converts corn kernels to ethanol.

The Midwest corn-to-ethanol industry is a major competitor to a growing California biomass-to-ethanol industry and also offers a base of relevant experience. If a California biomass-to-ethanol industry is to compete effectively with Midwest corn and with petroleum as sources of transportation fuel, such a new industry must effectively apply the lessons that both of these more mature industries have to offer.

In converting corn to ethanol, many of these lessons are explicit in the differences between the two major commercial methods, dry milling and wet milling.⁽⁴⁾ Corn kernels are composed of starch, sugar, oil, fiber, protein and ash. The starch and sugar constitute the 70%-75% of the corn kernel that can be converted to ethanol.

In dry milling, the entire corn kernel passes through the process used to convert the starch to ethanol. The solid residue containing protein is recovered for use as an animal feed known as distillers dried grain with solubles (DDGS).

The more modern wet milling approach first separates the corn kernel into its major components such as corn oil, corn gluten meal, corn gluten feed, and starch. All major components are converted into materials responsive to current market demand, and in particular, starch is converted into ethanol and other products. A wet milling plant is thus a corn-to-ethanol biorefinery.

Dry milling produces a higher yield of ethanol per bushel of corn than wet milling, but fewer value-added products. Dry milling is less capital-intensive, but also less profitable than wet milling. Several improvements are possible,

including more efficient processing of the hemicelluloses, and possibly even conversion of dry mills to modified wet mills (to be described later).

Wet milling now represents about 60% of all ethanol production. Corn is steeped to loosen the germ and hull fiber and separate the kernel into its components. The germ is crushed to enable the extraction of corn oil. Steepwater, germ meal, hulls and fiber can be combined to make corn gluten feed (CGF). The gluten from the kernel makes corn gluten meal, a high protein animal feed. The starch is converted to sugars that can be fermented to ethanol. Other possible coproducts include corn steep liquor, fiber, dextrose, and high fructose syrup. Interestingly, corn oil is the highest valued coproduct while ethanol is the most abundant.

Large-scale wet milling plants can now produce ethanol from corn at a cost up to 19 cents per gallon less than a dry milling facility. The steeping process can be further improved and the coproducts recovered with higher efficiency. Processing of corn kernels to ethanol and coproducts by either dry milling or wet milling is subject to the high and fluctuating costs of the feedstock.

In a variation of this process, modified wet milling eliminates some of the capital investment required for complete corn fractionation. Compared to standard wet milling, modified wet milling requires less capital investment, but still retains a significant value for coproducts.

Technologies for improving the corn-to-ethanol processes are being investigated. They include using corn residues, bacterial fermentation, improved fermentor design, semi-permeable membranes, improved distillation, and coproduct development. The agricultural residue, called corn stover (cobs, leaves, and stalk), is not yet processed commercially to ethanol, but if and when this is done, transportation costs from the Midwest to California will be a significant economic factor.

The technology of yeast fermentation from sugars such as molasses is simpler, involving the dilution of the molasses, introduction of yeast, fermentation, and distillation. A product of the sugar cane industry, molasses is widely used for fermentation to ethanol.

Thus, ethanol production from sugars is simpler than that from starches, which in turn is simpler than that from cellulosic materials (waste biomass). But sugars and starches have a higher economic value as food, while waste biomass has a low, sometimes negative, economic value, and the major costs presently associated with its use as a feedstock for conversion to ethanol and coproducts are often those of collection and transportation.

Why Should Ethanol Be Produced in a Biomass Refinery?

This section discusses some key issues regarding ethanol production in a biorefinery along with some examples of proposed biorefineries in California. A biorefinery produces ethanol and a variety of other products, such as electricity and chemicals, from biomass. (Appendix V-A provides a more detailed discussion of these topics.)

A California biomass-to-ethanol industry must compete with Midwest corn-to-ethanol and with petroleum fuels; both of these industries rely on a slate of products to maintain their present cost and pricing structure. A corn-to-ethanol company producing only ethanol, or a petroleum corporation producing only gasoline for automobiles, would not survive.

In these more mature industries, the cost of the delivered feedstocks range from 65 to 70 percent of the total production costs. Thus, the feedstocks must be optimally used, and the production of the various products must be adapted to meet current market demands. In biomass-to-ethanol biorefineries, these coproducts can significantly improve the process economics, while separating substances to facilitate further processing of the carbohydrate streams. Coproducts may be viewed as a means to add “upside potential” to the profitability of a plant producing ethanol and electricity from biomass. A California waste biomass-to-ethanol industry must make the best economic uses of the chemical components of its waste feedstocks. The industry should grow to adapt its output of various products to market demand.

With ethanol projects collocated with biomass electric power plants, the ethanol plant will buy electricity from the power plant and will supply the power plant with lignin as a high-energy fuel. Each is a customer of the other. This synergy from cogeneration results in reduced capital and operating costs that enable both plants to be more competitive. The next step is to produce, along with ethanol, a slate of other chemical products. As described earlier, three proposed California projects – the BC International Gridley and Collins Pine projects and the Sacramento Ethanol Partners/Arkenol project – plan to employ features of the biorefinery concept.

What Technology Improvements May Occur in a Mature Industry?

This section recaps the improvements in the process steps outlined above that could help develop a profitable biomass to ethanol industry in California. (Appendix V-A provides more details.)

Specifically, these improvements are in the following four areas: 1) improved pretreatment of feedstocks, 2) increasing use of genetically-engineered organisms for hydrolysis and fermentation of biomass, 3) integrating process steps to reduce capital and operating costs, and 4) producing ethanol from biomass in a biorefinery.

Within these primary trends, there are a variety of alternative, often complementary, research and development paths toward the goal of reducing the costs of producing ethanol from waste biomass.

Some of these are reduction of milling costs, pretreatments to make cellulose more reactive, a low-cost method for recycling cellulase, and higher temperature fermentation. A breakthrough in one of these areas has the potential to reduce difficulties in other areas.

Approaches that reduce the cost of making biomass fermentable have the largest potential economic impact. Consolidated bioprocessing is one preferred approach because “it offers the potential for a streamlined process that takes full advantage of the power of biotechnology for efficient and low-cost catalysis”.⁽⁵⁾ This path requires the development, through genetic engineering, of robust microorganisms that perform many functions in a single reactor.

What are the potential cost reductions for ethanol production that may result from the anticipated improvements in technology when these are incorporated into a mature biomass industry? In the literature, there are several fairly consistent estimates by respected scientists, engineers, and research organizations.

California has the potential advantage of using low-cost (waste) feedstocks, but the state may not be able to realize the advantages of scale accruing to larger plants (greater than 100 million gallons per year production). In petroleum and corn processing, about 65%-70% of the total production costs are attributable to feedstocks, so in this respect, the use of waste biomass is a significant advantage.

The above improvements in production costs do not include the effects of producing the ethanol in a biorefinery that benefits from the production of electricity and value added coproducts. To estimate the impact of biorefining on a mature industry, we use numbers provided by Elander and Putsche and by Katzen for the advantage in unit production costs of (more capital-intensive) wet-milling of corn, compared to the older dry-milling process.^(4,6)

Wet-milling facilities are corn biorefineries. They can produce ethanol from corn at a cost 10 cents to 19 cents per gallon less than dry-milling facilities that produce only ethanol and DDGS. The coproducts from waste biomass will be different from those from corn, but we will assume that they have a comparable impact on the cost of producing ethanol. When a single figure is required, 15 cents per gallon can be assumed as the estimated average reduction in cost of producing ethanol, when the ethanol production is accomplished within a biorefinery, but a range of zero to 30 cents per gallon cost reduction is plausible.

Chapter VII of this report provides more detail on the economic estimates of ethanol production from waste biomass in California.

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CHAPTER VI

ETHANOL PRODUCTION POTENTIAL FROM WASTES AND RESIDUES IN CALIFORNIA

VI. Ethanol Production Potential from Wastes and Residues in California

Introduction

This chapter combines the prior results for biomass resource potential from Chapter III and those from ethanol production processes of Chapter V to develop estimates of the maximum ethanol production potential from wastes and residues in California. This maximum production potential in California from these types of sources is well over 3 billion gallons of ethanol per year, but it is limited by many factors. The question is: what amount of this potential can be realized by effectively addressing the key technological, economic, and institutional issues?

Several major production considerations cause the practical total to be considerably less than the maximum calculated. These include geographic factors, plant size, infrastructure and distribution requirements, markets for electric power and coproducts, and other identifiable supports and constraints that will affect the size, profitability, and long-term viability of a biomass-to-ethanol industry in California.

One scenario for the growth of biomass-to-ethanol production in California is presented, but considering the large number of important unknowns, it is only an example.

What is the Maximum Ethanol Production Potential from Wastes and Residues in California?

The production potential is defined as the amount of ethanol that can be produced annually in California by converting all waste and residual biomass into ethanol transportation fuel. This is calculated by multiplying the total bone dry tons (bdt) of waste and residual biomass by the gallons of ethanol that can be produced from each bdt of material.

The most direct way to obtain an overall estimate of the annual ethanol production potential in California from waste and residual feedstocks is to multiply the total resource potential of approximately 50.7 million bdt of biomass (from Table III-1) by a conversion efficiency averaged over the plant operations for the various feedstocks and processes.

The average yield assumed for near- to mid-term conversions is 70 gallons of ethanol, plus electricity and coproducts, produced from one bdt of biomass. Multiplying 50.7 million bdt of waste biomass by the assumed conversion efficiency of 70 gal/bdt (approximately 64% conversion efficiency) gives 3.5 billion gallons as the estimated theoretical annual production potential. The major factors that will reduce this total are the collection, production, distribution, economic and institutional considerations that will be listed in subsequent sections of this chapter.

Table VI-1 Ethanol Production Potential* of Waste/Residual Biomass Resources in California (based on yields provided by M. Yancey and A. Aden of NREL)

Waste/Residual Biomass Resource Category	Million BDT (Annual)	Near-Term Yield** (gal/BDT)	Near-Term Production Potential (millions of gallons)	Mid/Long-Term Yield*** (gal/BDT)	Mid/Long-Term Production Potential (millions of gallons)
Paper (landfill)	8.7	63.0	548	95.3	829
Field and Seed Crop Residues	7.9	55.1	435	85.5	675
Chaparral	7.7	24.0	185	36.3	280
Lumber Mill Waste	5.5	59.5	327	82.5	454
Forest Slash	4.5	66.5	299	94.8	427
Urban Wood Waste	3.2	45.6	146	66.6	213
Fruit and Nut Crop Residues	3.0	49.0	147	72.8	218
Urban Yard Waste	2.9	45.6	132	66.6	193
Forest Thinnings	3.8	66.5	253	94.8	360
Food Processing Waste	1.7	43.6	74	64.4	109
Other	0.9	54.6	49	81.2	73
Vegetable Crop Residues	0.9	43.6	39	64.4	58
Total	50.70	51.5 (avg)	2,634	76.0 (avg)	3,889

* This assumes collection, delivery and processing of all the biomass with conversion to ethanol at the yields shown for each Resource Category, for each of the two time periods.

** Near-term yields are based on current NREL 2-stage dilute acid experiments and models. (Assumptions are tabulated in Appendix E)

*** Mid/Long-term yields are based on NREL projections for performance of the SSCF (1-stage dilute acid/1-stage enzymatic hydrolysis) process. (Assumptions are tabulated in Appendix E)

More detailed calculations of the maximum annual ethanol production potential from wastes and residues in California are shown in Table VI-1, based on near-term and mid-to-long-term yields provided by M. Yancey and A. Aden of NREL for each of the individual biomass resource categories in Table VI-1. The process assumptions used for the near-term calculations are based on NREL's current experiments and modeling of the 2-stage dilute acid conversion process. The assumptions used to calculate the mid-to-long-term yields are based on NREL projections for the SSCF process (one stage sulfuric acid, followed by enzymatic hydrolysis with simultaneous saccharification cofermentation). These assumptions are tabulated in Appendix VI-A.

The results, given in Table VI-1, are 2.6 billion gallons for the near-term, and 3.9 billion gallons for mid-to-long-term ethanol production potential from California waste and residual biomass, bracketing the 3.5 billion gallons theoretical maximum estimated above.

These more detailed figures are both large enough that the conclusion remains the same. The technological (collection, transportation, processing, distribution), economic (financing, competition, markets for products), and institutional (laws, regulations, incentives, agencies, interest groups) factors to be discussed in this section and later sections of this report, will determine the economically and environmentally sustainable size and profitability of a California biomass-to-ethanol industry.

The following sections of this chapter discuss some of the important considerations that affect the scope, distribution, and profitability of biomass-to-ethanol conversion facilities in California.

What is the Geographic Distribution of Possible Production Sites?

Proximity to available sources of waste biomass feedstocks will be a major consideration in the siting of California biomass-to-ethanol conversion facilities, such as collocation with existing municipal solid waste collection and processing sites. Collocation with existing biomass electric power generation facilities will be another. Proximity to markets is expected to be a weaker factor.

Most of the biorefineries operating on forest slash, forest thinnings, and lumber mill waste would be located in the northern portion of the state. The Northeastern California Ethanol Manufacturing Feasibility Study (1), also known as the Quincy Library Group (QLG) Study, provides much more detail on the relevant site selection criteria. Facilities to convert rice straw and hulls, walnut and almond shells, orchard prunings, and other agricultural wastes are likely to be located throughout the state, with many of them in the San Joaquin Valley, some near food processing plants. Biomass-to-ethanol plants using municipal solid wastes (MSW) as their feedstocks are likely to be located near existing MRFs (materials recovery facilities), large volume processing/transfer facilities, or landfills.

Data on active locations for collection and processing of all of these categories of waste biomass were obtained with the assistance of staff members of the California Integrated Waste Management Board. Some of the many possible sites for supplying waste biomass to biorefineries are tabulated in Appendix VI-B.

Biomass-to-ethanol plants using one or more components of the municipal solid waste (MSW) stream as their feedstocks will be geographically associated with the existing MSW collection, transfer, and processing infrastructure. Biorefineries are most likely to be located in close

proximity to MSW hubs that provide both on-site sorting capabilities and a sufficient volume or flow of materials to guarantee fulfillment of feedstock needs.

In urban areas of the state, such hubs are typically associated with large volume transfer and processing stations, or MRFs where MSW materials are aggregated on a regional basis, and then sorted and redistributed to a wide variety of commodity and residual disposal markets.

As collocation hosts, urban MRF/transfer stations can segregate a dedicated stream of cellulosic materials to the biorefinery partner appropriately tailored to ethanol production technologies. Feedstock suitable for acid hydrolysis technologies is currently available in separated and preprocessed form at many large MRFs throughout the state, particularly MRFs containing process lines that receive select paper-rich commercial loads. The residual waste streams from such sorting operations, which are currently transported to landfills, typically contain a high percentage of feedstock-quality waste paper.

The MRF/biorefinery collocation scenario may greatly enhance the potential of MSW for ethanol production, since the collection and processing infrastructures are already in place and separately funded. This makes it possible for biorefinery developers to partner with MRF operators by offering to accept a "tipping fee" at an adjacent ethanol plant which is less than the cost to transport and dispose of these same materials at competing landfills. In this collocation scenario, both partners benefit: the MRF operator by reduced or avoided disposal costs, and the biorefinery operator by negative feedstock costs.

In less populated areas of the state, or on urban fringes, major MSW hubs may be located at regional landfills. Such disposal facilities may also emerge in the future as biorefinery hosts where they can both attract and supply sufficient pre-sorted cellulosic feedstocks to an on-site ethanol plant, such as through preferred disposal rates for segregated loads at the landfill gate. Other potential economic benefits to the biorefinery partner may be available, such as the provision of landfill gas for boiler fuel, or the provision of electrical power or steam from landfill gas co-generation plants.

Non-combustion technologies for biomass conversion are defined in current state law in the same category with incineration, as "transformation" technologies, and are thereby limited to a maximum of 10% diversion credit toward meeting the mandated 50% recycling goal. If the non-combustion biomass-to-ethanol technologies were defined as "diversion" and made eligible for full diversion/recycling credits, this would provide a widely-dispersed selection of economically-attractive candidate sites for which the collection and separation infrastructures are in place. Some of these are listed in Appendix VI-B.

For conversion of forest wastes, six specific sites in Northern California were identified by the Quincy Library Group Study (1) for further characterization. The proposed locations are associated with existing or former sawmill sites in the towns of Anderson, Chester, Greenville,

Loyalton, Martell and Westwood, California. All of the sites except Greenville have access to existing biomass power plants and are large enough to host a new biomass-to-ethanol facility with adequate space for the storage of feedstock.

The Collins Pine facility at Chester in Plumas County was chosen in a California Energy Commission Public Interest Energy Research (PIER) competition for detailed investigation, probably leading to its development by Collins Pine Company and BC International to produce ethanol, electricity, and chemical coproducts. The site at Martell in Amador County is presently undergoing further study.

What Are the Important Features of Production Facilities?

The first biomass-to-ethanol conversion facilities planned for California are expected to process agricultural wastes (BC International, Gridley and Sacramento Ethanol Partners) and forest wastes (BC International, Collins Pine). They will be collocated with existing electric generation plants that supply them power, and to which they provide lignin-based fuels, to reduce both capital and operating costs. They will produce coproducts in order to lower their "net feedstock cost" for producing ethanol, and to increase the profitability of their operations. Subsequent plants may be collocated with MRFs, other waste collection facilities, and possibly near food processing plants.

These initial plants are likely to be relatively small, producing around 20 million gallons of ethanol per year. Some mid-term plants may be larger, perhaps 40-50 million gallons per year, and in the long-term, mature California industry, a few facilities could approach the size of modern corn-to-ethanol wet-milling operations in the Midwest that produce over 200 million gallons annually. This increase in plant size may be expected as the financial community gains greater confidence in the industry and in the increased profitability of larger operations. A limitation to this growth in plant size will be the capability to supply the larger plants with feedstocks collected economically from greater distances.

There are now in operation in California 28 biomass power plants (as displayed in Figure VI-1) owned by independent power producers. Many of these might benefit from synergies with collocated biomass-to-ethanol facilities. Most of these biomass power plants were built after passage of the Federal Public Utilities Regulatory Policy Act (PURPA) in 1978 and energy policies in California (Standard Offer contracts, etc.) provided suitable incentives. The industry grew to provide about 750 MWe in 1990.

Restructuring of the electric utility industry caused the utilities to buy out many of the Standard Offer contracts, reducing the biomass operating capacity to about 550 MWe. Many of the remaining facilities are now nearing contract "cliffs", after which they will receive about 4.5

FIGURE VI-1

**OPERATIONAL
BIOMASS POWER PLANTS
IN CALIFORNIA
1999**



Adequate water must also be available for processing the biomass to ethanol and coproducts. Air quality, water quality, and land use regulations must be complied with. Roads must exist for transportation of feedstocks and supplies to the plant, and for the distribution of products to customers. Electric transmission systems should be in place for the export of power.

The production capacities of the earliest California biomass-to-ethanol plants will be determined most strongly by the ability to obtain capital, and second, by the ability to obtain assurances for reliable, long-term supplies of low-cost feedstocks. The first may be affected by state actions, such as incentives or loan guarantees; the second will be determined by the types of feedstocks employed and the arrangements that can be made with the owners. In the case of forest wastes, this might include the U.S. Forest Service; for agricultural wastes, the supplier may be a regional farming cooperative; and for urban wastes, a municipality, waste management district, or a franchised MRF operator.

A combination of sources and feedstock types may often be used, for example, rice straw and wood wastes. In some plants it may be desirable to use a combination of agricultural, forest, and urban wastes to smooth the effects of seasonality of agricultural residues. Feedstock collection and delivery are elements of major importance in the plant economics, both because the cost of delivered feedstocks is often the single largest cost element, and because the scale of operations is determined by the size of the daily supply. The daily supply of feedstock, in turn, depends on the methods for harvesting, collecting, transporting, and storing the cellulosic material. This may be simpler for municipal solid wastes, where most of the collection and transportation infrastructure is already in place.

What are Important Considerations for Infrastructure and Distribution?

A biomass conversion plant is the central element in the larger ethanol production system, with many other necessary functions preceding conversion, operating at the site, and following the conversion of biomass into ethanol and coproducts.

Waste feedstocks must be delivered reliably to the plant. When long-term feedstock sources are established, the required collection, storage, and transportation mechanisms must be put in place.

Sources of electricity and process heat (perhaps from a collocated power plant), water for processing and cooling, chemical reagents and supplies, facilities for waste material and energy disposal, on-site and external roads, and the necessary environmental approvals must all be in place to support operations.

Contracts will have been written for sales of the plant's products, including the acceptance conditions (specifications) and delivery schedules. Since the biomass conversion facilities will produce ethanol and coproducts for which market demand and prices will vary, contracting may be a dynamic process, just as it is for corn- and petroleum-based product slates. The facilities for product distribution to local, regional, and more distant clients must be established.

Specific examples include facilities owned by the oil companies for blending ethanol with gasoline, for transporting the blend to the gasoline stations, and for distribution to consumers at the pump. All of these elements are part of the infrastructure necessary to support a California-wide biomass-to-ethanol industry.

Harvesting, collection, pre-processing, transport, and storage of feedstocks prior to conversion at the plant are among the most demanding aspects of the operation. Using forest wastes as feedstock requires that specialized equipment such as feller-bunchers and grapple-skidders be employed efficiently to keep costs down. Use of agricultural wastes requires dealing with the seasonality of harvests and provision of, or access to, adequate storage for stubble, shells, or other residue.

Processing of municipal solid wastes will usually require the least additional infrastructure, because systems for the transportation and collection of wastes at authorized locations are in operation. The separation of metals, glass, and plastics from biomass feedstocks, such as wood wastes, paper wastes, and yard wastes, has often already been accomplished, and can be done at additional sites for a negotiated price.

Some insight into the complexities, and also the opportunities that exist in harvesting and handling operations, is provided in a grant application (3) to the US Department of Agriculture by Prof. Bryan Jenkins of UC Davis, that he graciously made available to the CEC.

This document, entitled "Harvesting and Handling Rice Straw for Off-Field Utilization", lists a variety of individual operations, such as raking, swathing, baling, threshing, "roadsiding," hauling (including loading and unloading), storing, grinding, and cubing, not all used in one field. Several may be used in combination to provide optimum methods for in-field, central, or satellite processing. The choice depends on many factors including rice variety, straw moisture, field moisture, straw-to-grain ratio, equipment availability, utilization requirements, and of course, weather.

Many inefficiencies result from existing practices. For example, "Stack wagons often roadside bales in stacks that are too tall for a single truckload. Consequent restacking must occur which decreases productivity. In other examples, bale roadsiding equipment had high speed capability but slow hydraulic system performance that delayed the machine when picking up bales. These are areas in which some small and readily made equipment modifications might have significant impacts on capacity."(3)

It is not surprising that practices developed for the harvesting and handling of grain are non-optimum for the harvesting and handling of straw. If the transport and sale of rice field residues to biorefineries become significant economic and

environmental considerations for rice growers, residue management will evolve to become more economically and environmentally beneficial to the producers and the surrounding communities. Furthermore, equipment manufacturers may be motivated to develop specialized equipment for this growing market.

Storage of agricultural residues is an important issue for biomass-to-ethanol plants that operate year-round, because of the seasonal harvesting of the agricultural produce that leaves the residues. The residues used as biomass feedstocks may be left in the fields or collected for storage off-site. It is usually unsatisfactory to leave them uncovered in the fields for more than a few weeks, because the accumulation of moisture may cause deterioration and sometimes spontaneous combustion. The more common practice will be to cover the material with tarps or store it in barns for several months, until it is transported to a conversion facility.

Major elements of infrastructure at the conversion site include roads, water, and power. Availability of water is an especially important consideration because many of the steps in biomass conversion deal with dilute streams, containing relatively small quantities of material in much larger volumes of water. Process improvements, such as water recycle, would eventually reduce water usage.

Power production, conversion, and transmission facilities must also be available to support plant operations and to export any excess power to the regional grid. The availability of an existing power plant has been the determining factor in locating some of the first facilities (Collins Pine in Chester, and the Gridley project in Oroville). This is both because of the reduction in capital required for construction, and for the synergies in operation resulting from cooperation in supply of lignin-based fuel (from the ethanol to the electric plant) and power (from the electric plant to the ethanol plant).

Important elements of infrastructure must be in place for the sale and distribution of the ethanol, electricity and coproducts. The electricity may be used internally or exported to the regional grid. Development of contracts for the acceptance of ethanol, commodity and specialty chemicals requires a marketing effort that is broader and more adaptive than for the single product, ethanol.

There are also features of the operation of a biorefinery related to those established by specialty chemical and pharmaceutical manufacturers for the marketing and sale of small quantities of high-value products. Functions may evolve analogous to those required for efficient drug discovery, as biorefiners begin to explore the economic possibilities available from the various chemical fractions of their feedstocks.

What are the Requirements for Siting a Biomass-to-Ethanol Facility in California?

Siting a biomass-to-ethanol facility in California is a complex process, which can take 12 to 18 months or longer, depending on the issues specific to the site of the facility and the project's technology. Selecting the appropriate site will help minimize the cost

and time of siting a biomass-to-ethanol facility. (Appendix VI-C discusses this process in more detail.)

Typically, local government agencies, like a city or county planning department, will permit biomass-to-ethanol projects. Federal and state agencies will be the lead agencies in certain circumstances.

The lead agency will prepare an environmental impact report and determine whether the project complies with the California Environmental Quality Act.

The local air pollution district will review the project proposal to determine if the facility complies with the applicable air quality regulations and, if appropriate, will issue a permit to operate. Other agencies may also review and issue permits for biomass-to-ethanol facilities, though they will not be the lead permitting agency for the project.

The potential environmental impacts of biomass-to-ethanol facilities are associated with the harvest/gathering of feedstock and its transportation to the facility, as well as the construction and operation of the facility. The following are typical environmental concerns associated with siting an ethanol-to-biomass facility:

- wastewater that must be adequately treated and disposed
- hazardous and nonhazardous wastes, their use, creation, and disposal
- noise and odor
- biological resources issues concerning impacts to sensitive species and their habitat
- air pollution
- water availability and use

Other important issues include transportation and land use impacts and the potential to impact visual and cultural resources.

What are Some of the Primary Constraints and Challenges?

In the usual biomass parlance, the technological, economic, and institutional factors that affect the viability of individual biomass-to-ethanol projects and the expansion of the industry are referred to as barriers. Here they are considered simply as constraints and challenges, conditions of the real world that must be understood, evaluated, and adapted to or modified, if California is to realize an economically and environmentally sustainable biomass-to-ethanol industry. Here is a list of some of these factors,(4) outlined below:

Technological Considerations: feedstock characteristics, seasonal availability, residue collection; feedstock production, storage, and processing; process scale-up; material erosion and corrosion.

Economic Considerations: production costs, capital costs, enzyme costs, costs of delivered feedstocks, competing markets for residues, and costs of environmental compliance.

Environmental Considerations: effects on the soil, ecological impacts, air emissions, water usage, wastewater treatment, environmental permitting, endangered species, harvesting agricultural residues, ash disposal, truck traffic and related emissions, noise and odor, and energy use.

Institutional Considerations: incentives to producers and users, permitting requirements, emission offset requirements, availability of residues on a long-term basis, cooperation among agencies, long-term supportive state regulations.

Some of the more significant economic and institutional constraints are:

- (a) Access to bank loans, which could be alleviated by legislative authorization of 10- to 15-year loan guarantees for construction and operation of biomass-to-ethanol facilities.
- (b) Access to MSW, which could be alleviated by redefining non-combustion technologies to receive full credit toward the goal of 50% diversion.
- (c) Need for a long-term, unified, supportive state biomass-to-ethanol policy, perhaps coordinated through a consortium of the responsible agencies.
- (d) Need for reliable, long-term contracts for supplies of low-cost waste biomass feedstocks, a problem that might solve itself, if the above constraints were mitigated.

A Scenario

Much has been said in this chapter and elsewhere in this report about the conditions that would nurture the growth of a biomass-to-ethanol industry in California. This section makes a small number of key assumptions about the conditions bearing on the growth of a California biomass-to-ethanol industry over the next decade, and projects one scenario of many possible scenarios that portrays a middle course toward the usage of biomass-based ethanol as a transportation fuel.

The first, and most important assumption is a unified state policy, Item (c) above, that might include the first two actions in the list, and make the fourth possible.

The second set of assumptions concerns competition. Ethanol from Midwest corn will initially supply California market requirements. Ethanol from California waste biomass and from Midwest corn stover will then win increasing shares of the market from Midwest corn. California waste biomass will eventually earn the predominant market share over Midwest corn stover because of transportation costs, and perhaps by adopting more advanced technologies. Brazilian

ethanol from sugar cane will be kept out of the competition by continuing the 54 cents/gallon tariff on imports of ethanol.

No technological breakthroughs are assumed, although some may occur. Present laboratory and pilot scale processes are brought successfully to commercial-scale operation. Improved enzymes are produced at lower cost. More efficient feedstock collection and sorting (e.g., collocation of biomass-to-ethanol facilities with MRFs) develops as a common industry practice.

National and state policies support ethanol as an additive to gasoline during the decade from 2000 to 2010. After 2010, these policies remain the same or perhaps become supportive of E85 and neat ethanol as transportation fuels, if the costs of their production are sufficiently reduced.

Estimates of the market demand for ethanol as a gasoline blending component in California range from 148 million to over 1 billion gallons per year (see Chapter II and Appendix II-B). Perhaps an intermediate figure of 300 to 500 million gallons annually is most likely. In any event, the California waste-based biomass-to-ethanol industry will have to compete with the Midwest corn-based biomass-to-ethanol industry for this market.

The technological, economic, and institutional factors discussed in this report are important in determining the market percentages of these competing sources during the years 2000 through 2010. They thereby influence the number and the capacity of California plants that can compete profitably. A 65% share of a 300 to 500 million gallon ethanol market (195 to 325 million gallons annually) in the middle of the decade would support about 10 to 15 plants of 20 million gallons capacity in California using urban, agricultural, and forest wastes to produce ethanol, electricity, and coproducts.

Timing is always difficult to predict, but an “S-shaped” curve is the usual pattern for a growing industry. A projection of sales of ethanol produced from California waste biomass under the preceding scenario might take the following form: 50 million gallons in 2003, 250 million gallons in 2005, 700 million gallons in 2007, approaching 1 billion gallons in 2010.

The 1 billion gallon level could be less or more depending on the policies that are enforced and the technologies that are implemented between now and 2010.

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CHAPTER VII

ECONOMIC EVALUATION

VII. Economic Evaluation

Introduction

This Chapter evaluates the economics of cellulosic biomass to ethanol production in California compared with obtaining ethanol from sources out-of-state, grain-based. The following topics are covered:

- Approach to assessing economic analysis of ethanol from biomass
- Cost to produce ethanol at conventional grain-based facilities
- Near- and short-term costs to produce ethanol in California
- Assumptions for the cost of feedstocks to California biomass
- Assumptions in economic analysis
- Modeling results for California biomass ethanol production costs
- Long-term California ethanol production costs

What are the Approaches to Assessing the Economic Analysis?

This analysis includes a number of different production scenarios, which incorporate different feedstock and process options along with other implications such as employment.

Ethanol production costs were estimated for corn dry milling and wet milling process for the near-term, mid-term and long-term timeframes (2002, 2007 and 2012). Production costs were then estimated for four types of California biomass, using two technologies in the three timeframes. Finally, the economics of ethanol-only facilities are compared to collocated facilities.

What are the Costs of Ethanol Produced in Conventional Ethanol Production Facilities?

The costs of ethanol produced in corn-based plants were estimated to form a benchmark.

The newest of these plants use the latest wet milling processes integrated with electric power generation, and food and animal feed products. Resulting ethanol prices are affected by feedstock prices, (plant size, operating costs, interest rates, etc.) the markets for coproducts, and other factors.

ProForma Systems modeled both dry milling and wet milling processes to provide a comparison with fuel ethanol produced in California from cellulose-

based feedstocks. Ethanol production costs for corn dry milling and wet milling were determined with ProForma Systems' proprietary Virtual Process Simulator that allows rapid and detailed analysis of chemical and biological processes. Each model is based on detailed process flow diagrams for the respective ethanol production technology. Production costs include plant operation, feedstock and debt service.

Several factors affect the economics of ethanol production from corn using the dry or wet milling process. These include corn prices, value of the coproducts, and the size of the ethanol facility. Many states also have ethanol production or use incentives that improve the economics for many smaller ethanol facilities.

To estimate ethanol production costs in the near-term, the corn price is assumed to be \$2.50 per bushel and the distillers' dried grains value is assumed to be \$85 per ton. For a 20 million gallon per year dry mill, the resulting production cost is \$1.23 per gallon. For a 200 million gallon per year wet mill, the near-term ethanol production cost is estimated to be \$0.97 per gallon (with the value facility of wet mill coproducts gluten meal, gluten feed and germ at \$240, \$65, and \$250 per ton, respectively).

Figure VII-1 shows the sensitivity of ethanol production costs, both dry and wet milling, to corn prices. For dry milling at 20 million gallon per year plant size, ethanol costs range from \$1.09 to \$1.71 per gallon for corn prices from \$2.00 to \$4.00 per bushel. For wet milling at 200 million gallon per year plant size, ethanol costs range from \$0.88 to \$1.50 per gallon for corn prices from \$2.00 to \$4.00 per bushel.

Figure VII-2 shows the sensitivity of ethanol production costs, to plant size. Dry mill ethanol production capacities are typically in the range of 10 to 30 million gallons per year with two existing dry mill facilities at 65 and 75 million gallons per year. Wet mills are typically much larger, ranging from 50 to 200 million gallons per year or larger.

With corn at \$2.50 per bushel, ethanol production costs range from \$1.35 to \$1.07 for dry mill plant sizes from 10 to 75 million gallons per year. For wet mills, ethanol production costs range from \$1.14 to \$0.97 per gallon for plant sizes from 20 to 200 million gallons per year.

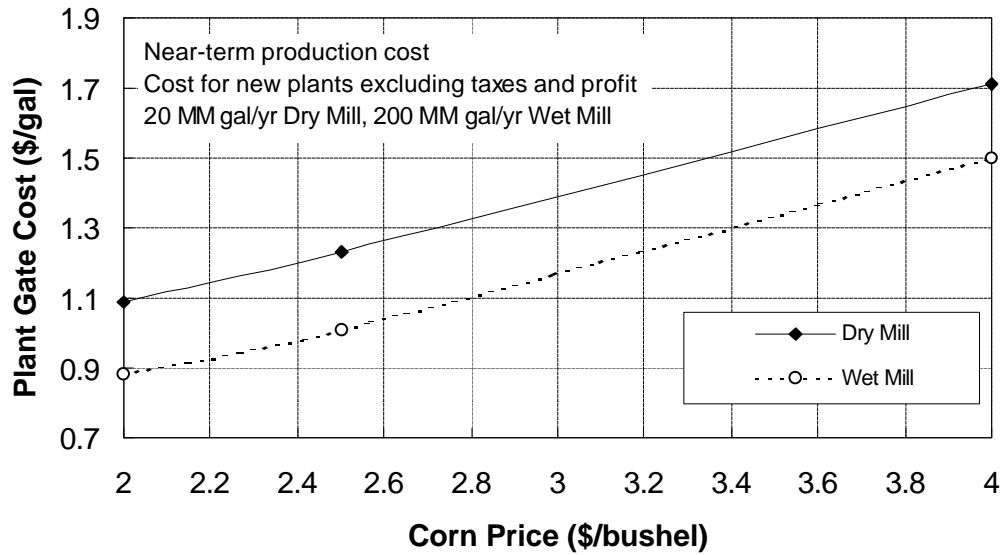


Figure VII-1. Ethanol cost sensitivity to corn price
Source: Evaluation of Ethanol Production Costs, Appendix VII-B

Dry and wet milling ethanol production costs are assumed to decrease in the mid- and long-term scenarios. Improvements will likely be in the areas of increased ethanol yields per bushel of corn, the development of higher value coproducts, and reduced operating costs. Dry milling ethanol production costs are estimated to be \$0.98 to \$1.26 per gallon in the long-term. Wet milling ethanol production costs are estimated to be \$0.91 to \$1.04 per gallon in the long-term. Since the cost of production includes debt service, older plants may have a lower marginal cost of production as capital is depreciated.

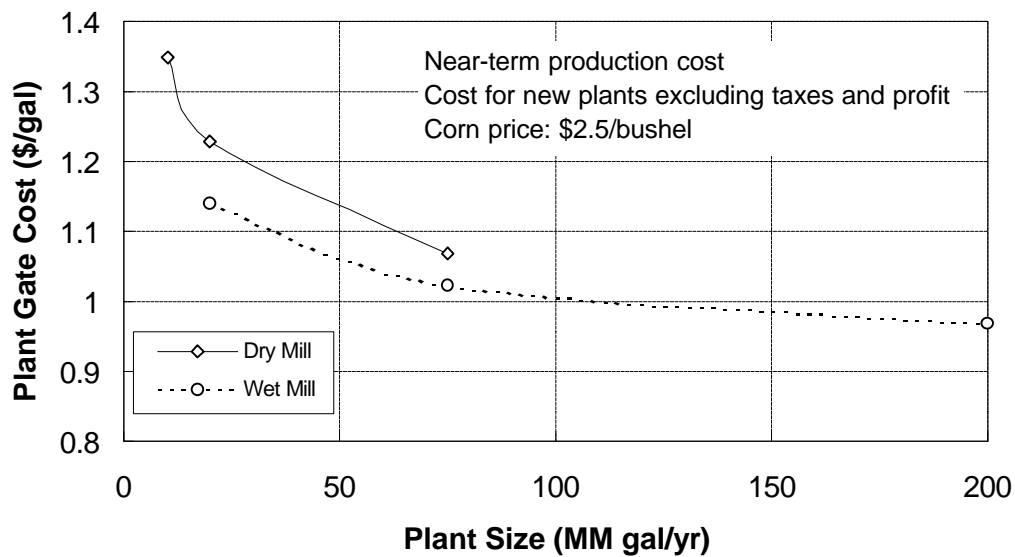


Figure VII-2. Ethanol cost sensitivity to plant size

What are the Short and Intermediate-Term California Ethanol Production Costs?

As discussed in Chapter V, several cellulose conversion options have been analyzed for feedstocks in California. These analyses have shown similar production costs among several near-term technologies to convert biomass to ethanol, assuming the same level of technology maturity.

The National Renewable Energy Laboratory (NREL) has undertaken extensive evaluations of ethanol production.⁽¹⁾ Figure VII-3 shows a comparison of production cost estimates for the leading technologies. These estimates indicate that the cost to produce ethanol, for a fixed set of assumptions, overlaps considerably between the different technologies. These costs depend on several factors including site-specific details, feedstock composition, and enzyme costs. Ethanol production costs are comparable for two-stage dilute acid, concentrated acid, and enzyme processes. Gasification results in an improved product yield and projected lower cost; however, the technology is developmental.

The success of a future commercial biomass industry is likely to depend more on feedstock costs and improvements in process technologies that apply to several technologies rather than which technologies are used. For the purposes of these evaluations, the two-stage dilute acid and enzyme process were used to estimate production costs. The two-stage dilute acid process is the closest to commercial technology and has been selected for several projects. At this point, it is difficult to project which technologies will be the most economic in the long-term because technological improvements in the biological processes will increase the ethanol production and reduce enzyme costs. The enzyme process can achieve improved overall economics compared to the two-stage dilute acid process if ethanol yields are increased and enzyme costs are reduced.

Gasification/fermentation has the potential for the highest yields and lower estimated production costs as the lignin fraction of the biomass can also be converted to ethanol. This technology is experimental and the outlook for commercialization cannot be accurately assessed at this time.

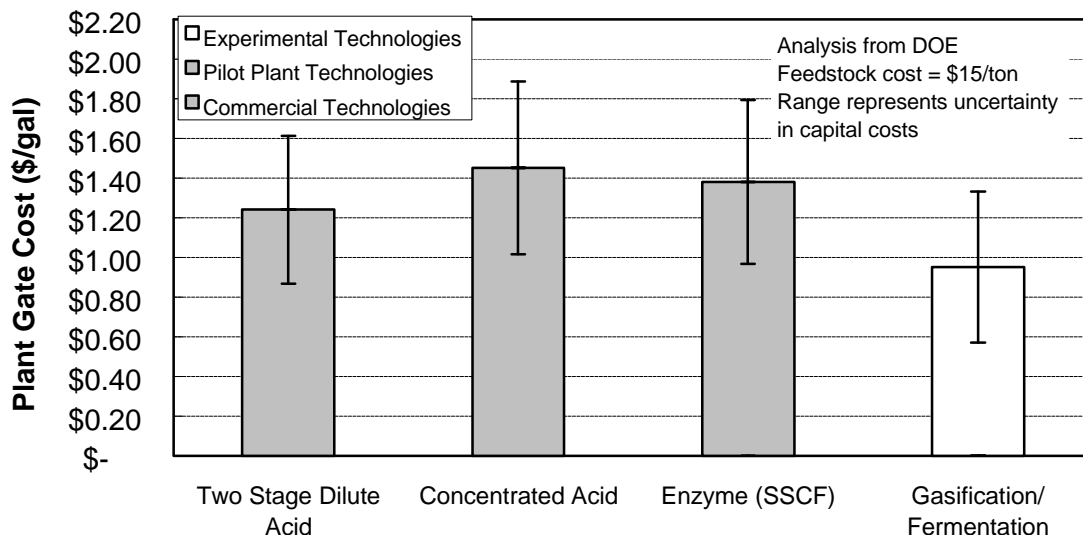


Figure VII-3. Comparison of Ethanol Production Cost Estimates. Source: DOE (1)

The economics of ethanol production in California were estimated for the plant types shown in Table VII-1. The analysis included scenarios involving different feedstocks, locations, plant types (including grass roots and collocated plants), plant operating assumptions, time frames, and other factors. The following categories of feedstocks were considered:

- Forest thinnings and timber harvest residues,
- Agricultural residues,
- Urban waste,
- Waste paper, and
- Eucalyptus trees as an example of energy crops

These categories represent large potential sources of biomass in California.

Table VII-1. Biomass plant configurations for modeling and economic evaluation.

Technology	Plant Type
2-stage dilute acid	grass roots
2-stage dilute acid	collocated
Acid/enzyme (SSF)	grass roots
Acid/enzyme (SSF)	collocated

The analysis covered three timeframes—near-, mid- and long-term (2002, 2007 and 2012). The two-stage dilute acid and the acid/enzyme technologies as well

as other biomass-to-ethanol conversion technology options are discussed in detail in Chapter VI.

As discussed in Chapter V, biomass-to-ethanol conversion technologies are in their infancy and significant reductions in ethanol production costs are expected as the technologies mature. Over the long-term, ethanol production in California will evolve towards improvements in processing technology. As experience is gained in biomass-based production, the net costs to produce ethanol are expected to be reduced because of increased ethanol yields, reduced enzyme costs, and additional value-added coproducts.

Because there are no commercial biomass ethanol plants in operation, numerous assumptions are required to estimate biomass ethanol production costs. Several variables affect the cost to produce ethanol, including the feedstock price and composition, plant size, ethanol and coproduct yields, coproduct credits (revenues), capital and operating costs, and project financing. The following provides more detail on the assumptions for the two-stage dilute acid technology and acid/enzyme technology analysis in the near-, mid- and long-term. Appendix VII-B presents more detail on the economic analysis.

Feedstock Cost Assumptions for California Biomass Ethanol

The cost and quality of feedstocks are key parameters that affect the cost of ethanol production. The outlook for feedstock costs for forest materials, agricultural materials, urban waste, and energy crops was considered for near-, mid- and long-term time horizons. Feedstock prices are likely to be affected by the size of ethanol plant as transportation costs increase as material must be transported for a larger distance to the plant. It is likely that most ethanol plants would operate on a mixture of feedstocks to adjust for seasonal availability and take advantage of the lowest price materials.

Some feedstocks like forest thinnings and rice straw can potentially receive subsidies that reflect economic and environmental benefits that would not be realized if these materials were not transformed to ethanol. The effect of eliminating subsidies in the mid- and long-term were considered. Detailed assumptions on feedstock costs are presented in Appendix VII-A.

Lumbermill waste and forest thinnings were considered for plants operating on forest material. Removing biomass from forests that have a high risk of fire costs about \$47/ton. The benefits of harvesting forest thinnings also include increasing water available for larger trees, reduced fire fighting costs, and potentially reducing insect damage. For ethanol plants located adjacent to lumber mills, it was assumed that a limited quantity of lumbermill waste could

be purchased for \$20/ton and lignin sold at an equivalent energy value (\$25/ton). Forest thinnings and forest slash were assumed to be the balance of the feedstock. Electric power could be purchased from a collocated plant for \$0.05/kWhr, while a higher purchase price of \$0.08 that includes distribution costs, was assumed for grass roots plants.

While converting forest material to ethanol has the potential to provide for environmental benefits, there are some challenges for using this material for an ethanol plant. Providing a steady amount of forest material year round is not always possible as environmental constraints limit timber harvesting to non-rainy months. The amount of forest material that could be available in proximity to a potential ethanol plant limits the plant size to about 40 million gallons per year. Several ethanol plants in this size range could be feasible in Northern California.

A combination of rice straw, orchard prunings, other agricultural waste, and urban tree trimming material was assumed as a feedstock for plants operating on agricultural residues. Materials such as orchard prunings are expected to be relatively expensive as these are also feedstocks for biomass power plants. Other woody agricultural materials, as well as suburban tree prunings, were considered as feedstocks.

Rice straw cannot be burned in power plants as its silica content is too high. For an ethanol plant operating on a rice straw mixture, disposing of the lignin and solids poses a problem as the remaining solids would contain high levels of silica that would erode power plant boilers if burned. Consequently, the plant is expected to operate part of the year on rice straw and the lignin would be disposed of as a soil amendment for a transportation cost of \$10/ton. Arkenol has developed a process for separating the silica from rice straw and refining it as a high value coproduct for their concentrated acid process. While the economics of this process were not evaluated, it provides another approach for using rice straw as an ethanol feedstock.

Currently, a tax credit of \$15/ton is available for a limited quantity of rice straw in California. The tax credit is intended to help defer the cost of not burning rice straw in fields. The economic effect of different amounts of rice straw in the feedstock mix was analyzed, with less rice straw used in the feed mix if the tax credit was not available.

Ethanol plants using urban waste feedstocks were assumed to operate on a mixture of urban wood waste, tree trimmings, and waste paper. A dedicated waste paper feedstock was also considered. An urban waste-based facility could be located at a municipal solid Waste (MSW) processing facility. This siting

would minimize transportation costs and provide access to a wide array of feedstocks. A combined MSW processing and ethanol facility would not likely be located with an existing biomass power plant; therefore, feedstock costs would be higher for facilities located at biomass power plants.

Waste paper may also be available from material recovery facilities, which serve as separation and transfer stations for urban waste. Locating the ethanol plant at such a facility would reduce transport costs and disposal costs. Many waste streams, such as office waste, contain a high portion of waste paper. The paper that is not recycled is more likely to be contaminated with food waste, grease, liquids, and other materials but still useable for ethanol production. There are not many competing uses for contaminated paper. Such facilities may handle up to 360 tons of paper per day. This quantity is sufficient for a small ethanol plant. Supplemental feedstocks, such as yard waste and tree chips, as well as urban wood waste, would provide sufficient material for a 30 million gal/year plant. Larger waste processing facilities in Southern California could possibly support a facility that produces over 100 million gal/year. Newspaper is currently recycled and has a relatively high value and would not be economic for ethanol production.

A key feature of MSW based ethanol production may be the integration of the feedstock recovery with the ethanol plant. Loads of waste can be directed towards the ethanol facility if they contain a sufficiently high paper content. Waste from the ethanol facility could then be disposed of with materials that are not suitable for ethanol production or burned to produce steam for the ethanol plant. In an urban environment, permitting a boiler for burning MSW residue may not be feasible, so natural gas or land fill gas may be used to produce steam for the ethanol plant.

MSW to energy facilities also operate in California with a total capacity of about 170 MW. Such facilities may be suitable for ethanol production since they are already permitted for burning MSW, but such facilities generally do not have MSW sorting capabilities.

Wood waste, tree trimmings, and yard waste are separated in many areas and would be suitable feedstocks for ethanol production. Competing uses for the highest quality of urban wood waste would require blending with lower value feedstocks, such as tree prunings, to reduce feedstock costs. Most urban wood waste that is currently burned in biomass power plants consists of larger branches from tree pruning and removal with very little clean wood residue from furniture and lumber operations. Urban wood waste is a limited resource for existing biomass power plants and if used as an ethanol feedstock the price and transportation distance would increase. If lignin from ethanol production

proves to be a suitable fuel for biomass power plants, the lignin could replace some of the feedstock for power plants and eliminate the potential competition for a limited resource.

Chipped tree branches and yard waste are other potential feedstocks. These materials are either composted or used for landfill cover and are not suitable as fuels for biomass power plants. Sorting and quality control steps may need to be taken with branches and yard waste as these can quickly rot, may contain unexpected contaminants, and can have a high ash content.

Energy crops could provide additional feedstocks for ethanol production. Eucalyptus was assumed as a potential energy crop since it has low water requirements and could be grown in many parts of California. It also could be used in areas where ground water contamination may be mitigated by planting trees. Near- or mid-term energy crop scenarios were not considered as several years are required to establish an initial harvest.

Economic analysis assumptions

Table VII-2 shows the key assumptions for the economic analysis. Mixes of feedstocks were evaluated for each category of biomass. In the near and mid-term, subsidies for the feedstocks with environmental benefits were assumed to be available. Subsidized feedstocks comprised 50 to 81 percent of the mix of biomass for ethanol plants in the 40 million gallon per year capacity forest material and agricultural residue cases.

In the analysis, many factors were assumed to vary with the time frame such as the ethanol production yields, enzyme costs, and risk associated with building an ethanol plant. Mid-term feedstock costs are summarized in Table VII-3.

The process assumptions for the near-term scenarios are based on research by the National Renewable Energy Laboratory (NREL), including processes such as hydrolysis sugar yields, fermentation ethanol yield, and the two-stage technology. These near-term values have been demonstrated by bench- and pilot-scale tests at the NREL.

Table VII-2. Summary of key assumptions for economic analysis

Category	Feedstocks	Feedstock Subsidy (\$/ton)			
		Near	Mid	Mid	Long
<u>Subsidy Assumptions</u>		Yes	Yes	No	No
Forest Material	Forest thinnings	30	30	0	0
	Lumbermill waste	0	0	0	0
Agricultural Residue	Rice Straw	15	15	0	0
	Agr. Waste, wood waste	0	0	0	0
Urban Waste	Waste paper, wood waste, others	0	NA	0	0
Energy Crops	Eucalyptus	NA	NA	NA	0
<u>Economic Assumptions</u>					
Equity Ownership (%)		25	25	25	25
Interest rate on Debt (%)		8	8	8	8
Construction Contingency (%)		30	10	10	10
Hurdle rate (%)		30	25	25	20

NA = not applicable. Feedstock was not evaluated in this timeframe

Source: *Evaluation of Feedstock Costs, Appendix VII-A*

Table VII-3. Summary of feedstock cost assumptions

Feedstock Category	Composite Cost (\$/ton)		Feedstock Materials	Cost (\$/ton)
	Yes	No		
Subsidy Assumption				
Forest Material (collocated cases)	18	42.2	Forest thinnings Lumbermill waste	47.5 20.0
Agricultural Residue	19.5	27	Other Ag. Waste Rice Straw Orchard prunings	13.4 27.9 31.0
Urban Waste	NA	15.4	Separated waste paper Yard waste Urban wood waste Tree pruning chips	15.7 10.2 18.6 13.1
Waste Paper (stand alone cases only)	NA	-4.3	Separated waste paper	-20 to 0
Energy Crops	NA	43.6	Eucalyptus	43.6

Source: Evaluation of Feedstock Costs, Appendix VII-A

Feedstock costs for mid-term 30 to 40 million gal/year ethanol capacity. Transportation costs vary with plant size. Larger plant sizes require more feedstock and greater transportation distances. Small urban waste plants can obtain low cost waste paper feedstocks if located with a material recovery facility.

The mid- and long-term values are hypothetical, based on engineering judgments. The mid-term case includes using the limits of theoretical yields for two-state dilute acid technology using hydrolysis reactors. The long-term case includes using improved technology such as counter-current hydrolysis. Some

of these technologies are also being implemented in the paper and textile industries.

The required sales price of ethanol at the plant gate was calculated for a fixed hurdle rate that was reduced over time. (This price is referred to the target price in subsequent discussions, as the actual price will depend upon market conditions.) In the short-term, a higher hurdle rate was assumed to be necessary to attract investors to a riskier technology. As the technology matured and risks diminished, the required hurdle rate was assumed to decline.

Coproducts generated in this process can significantly lower the net production cost of ethanol. Lignin used as boiler fuel is the only coproduct assumed to be sold. In the mid- and long-term, the effect of selling higher value chemicals was evaluated. Some near-term facilities are basing their economics on the sale of coproducts; however, such projects represent relatively small volumes of chemical sales and the outlook for coproduct sales from a large fuel-based ethanol infrastructure remains uncertain. The sale of chemicals produced from the hydrolysate sugars and/or from the lignin, as well as high value chemical production from biomass extractives were also analyzed and presented in Appendix VII-B. While the sale of some coproducts seems likely, it may not be desirable to base a policy on the sale of products that are not well defined.

Two-stage dilute acid technology assumptions

Fermentation of the six carbon sugars (e.g., glucose) plus xylose sugars to ethanol in the near-term case is assumed to be accomplished with genetically engineered yeast or bacteria. The ethanol fermentation yields for the mid- and long-term cases assume the use of an improved genetically engineered yeast or bacteria which utilizes all five biomass sugars: glucose, xylose, mannose, galactose and arabinose with increasingly higher yields.

For the near-term to long-term plants, ethanol production yield were assumed to increase with improvements in hydrolysis and fermentation. With forest material, the results were an increase from 84 to 101 gallons per ton for the two-stage dilute acid process from near-term to long-term plants. The yield depends on the amount of fermentable sugars in the feedstocks. The lowest yields are associated with rice straw and the highest yields are associated with clean paper.

Prior studies by the NREL considered single stage dilute acid processes with a near-term yield of 52 gallons per ton in the near-term. Early two-stage processes had only slightly higher yields. However, current pilot plant data supports the estimate of 84 gallons per ton for forest materials.

The ethanol yields in this case are equal to those obtained in the laboratory by NREL for two-stage dilute acid hydrolysate. Increasing fermentation temperatures are also assumed as new technology is developed. Higher fermentation temperatures will reduce the process energy use and increase the rate of fermentation.

Acid/enzyme technology assumptions

The NREL has conducted bench- and pilot-scale test to determine many of the near-term process values. The mid- and long-term values are hypothetical, based on engineering judgment, with the goal of reducing the overall cost of ethanol production. For enzymatic conversion plants the yield is expected to improve from 97 to 105 gallons per ton from the mid-term to long-term time horizon with forest material feedstocks.

Acid/enzyme technology modeling assumptions for the near-term scenarios are based in large part on research conducted by the NREL. A simultaneous saccharification and co-fermentation (SSCF) process has been modeled as opposed to other enzymatic technology options such as separate hydrolysis and fermentation. Key ethanol production parameters include pretreatment effectiveness (hemicellulose sugar yields and reactivity of the remaining solids to enzymatic hydrolysis), cellulase enzyme productivity and activity, SSCF sugar and ethanol yields. Many of the near-term process values have been demonstrated by bench- and pilot-scale tests at NREL. Mid- and long-term values are hypothetical values based on engineering judgement and NREL's goals for reducing overall ethanol production costs.

Collocated Ethanol Facility Assumptions

Collocating biomass ethanol facilities with existing biomass power plants can result in several interfaces that can have significant economic benefit to each facility. These interfaces can reduce capital cost of the ethanol facility, decrease fixed and variable operating costs for both facilities, create new revenue streams for existing biomass power plants, and make both facilities more competitive in their respective markets. The interfaces and corresponding economic benefits of collocating ethanol facilities with existing biomass power plants will likely vary somewhat from site to site.

A collocated facility has several economic advantages. The cost of processing feedstocks is shared for both facilities. The ethanol facility can contract with the biomass power plant to manage feedstock procurement and inventory which reduces the fixed operating costs for both facilities. The ethanol plant can also process feedstocks that would be burned in the biomass power plant and provide

lignin as a fuel for the power plant. For a stand alone facility, lignin could be burned in a boiler to generate steam, but excess lignin would need to be transported to a biomass power plant which would reduce the potential income from the lignin. Handling and transaction costs for lignin are minimized with a collocated facility.

Modeling Results for California Biomass Ethanol Production Costs

Ethanol production costs presented below were determined with ProForma Systems' proprietary Virtual Process Simulator. Each model is based on detailed process flow diagrams for the respective ethanol production technology. Stand-alone and collocated biomass ethanol facilities are also analyzed with the simulator.

Table VII-4 shows the cost and target sales price estimates for mid-term production scenarios using the two-stage dilute acid process. (The ethanol target price represents the sales price that would cover capital and operating costs and provide the rates of return indicated in Table VII-2. This price value can be compared directly with the projected price of ethanol from out of state sources discussed in the following subsection to assess if in-state ethanol production can be economic.) The values correspond to the median plant sizes. In the mid-term, cost estimates are lowest for the collocated facilities using the two-stage dilute acid process. Costs for the acid/enzyme process are notably higher. Long-term costs are much lower as enzyme costs are reduced.

Table VII-4. Mid-term ethanol production cost estimates^a.

Feedstock	Capital Investment (\$ Million)	Cost of Production	Target Price
Forest Material, no Subsidy	75	\$0.95	\$1.18
Forest Material, with Subsidy	75	\$0.66	\$0.90
Agricultural Residue, no Subsidy	109	\$1.09	\$1.44
Agricultural Residue, with Subsidy	109	\$1.03	\$1.37
Urban Waste	87	\$0.83 to \$0.85	\$1.19 to \$1.21
Waste Paper	76	\$0.47	\$0.77

^a Estimates for 2-stage dilute acid process. 40 million gallon/yr plants for forest and agricultural materials. 30 million gallon/yr plants for urban waste. Stand alone urban waste plant is located with a material recycling facility.

^b Feedstocks costs can be lower for ethanol plants integrated with a material recovery facility. For larger plants, waste paper must be obtained from other facilities.

Source: Evaluation of Ethanol Production Costs, Appendix VII-B

Several key variables were evaluated to show the sensitivity of ethanol production costs, including:

- Ethanol plant size
- Delivered feedstock cost
- Feedstock composition
- Ethanol selling price
- Ethanol facility capital cost

Of the variables evaluated, the cost of the feedstock has a very important effect on the economics of ethanol production. Production economics were analyzed for feedstocks with and without subsidies shown in Table VII-2. Materials that could potentially be subsidized (forest thinnings, rice straw, and waste paper) were estimated to make up 50 to 80 percent of the feedstocks.

Figure VII-4 illustrates the effect of feedstock costs on the target ethanol price. In the case of forest materials, a wide range of feedstock costs could occur as some or all of the feedstock could be obtained from land where thinning of the forest is subsidized. Mid-term ethanol prices would be reduced as yields improve and if facilities are expanded to 40 million gal/year.

An ethanol plant located with a material recovery facility may be able to obtain waste paper feedstocks in the range of -\$20 to \$0 per ton after clean up costs are taken into account. The target price for such a facility based on the two-stage dilute acid process is \$1.62 to \$1.90/gal in the near-term for a 10 million gallon per year plant. The relatively small size, requirement for a high contingency for an emerging technology, and requirement for a natural gas boiler to generate steam results in a higher cost of production than that of a mid-term plant.

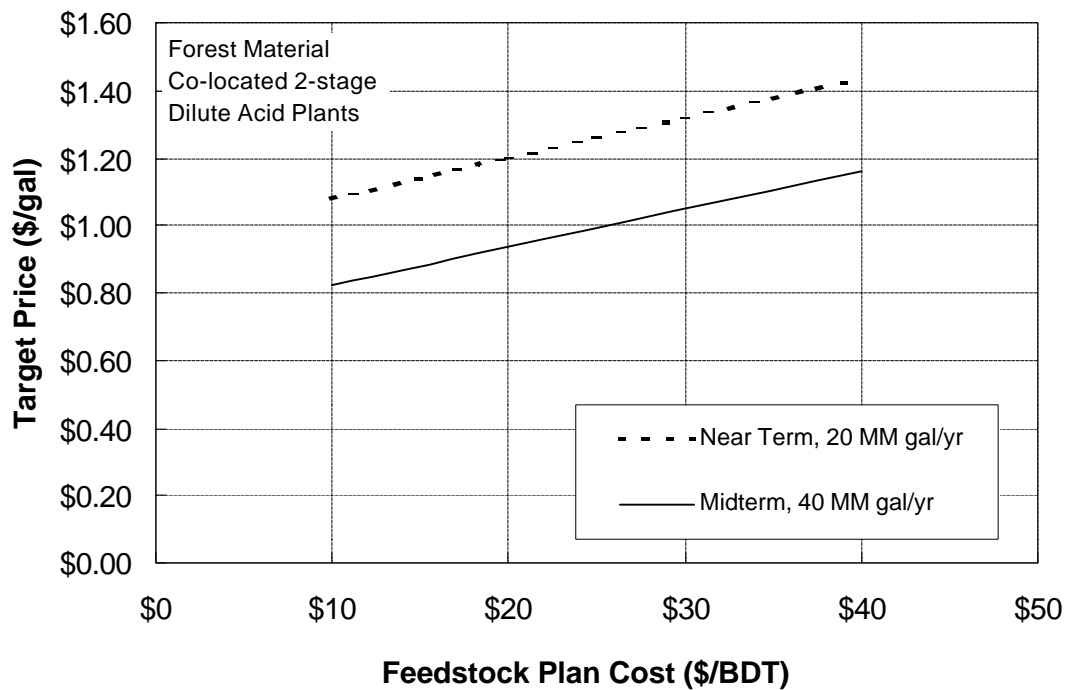


Figure VII-4. Relationship between forest material feedstock cost and ethanol price. Source: Appendix VII-B

The effect of the cost of waste paper is illustrated in Figure VII-5. Costs associated with sorting or maintaining a long-term supply of the feedstock could cause the cost of waste paper to be higher than a nominal disposal cost of - \$20/ton. This analysis considers an ethanol facility that is not located with a biomass power plant. Steam would need to be generated from natural gas. Using waste paper at an MSW burning facility would result in even lower costs of production if steam generation, waste water treatment, and MSW sorting capabilities were present at the site.

While production costs are higher for a near-term 10 million gallon per year facility, such a scale may be desirable. The facility would be eligible for an additional \$0.10/gal tax credit. Also, operating a smaller ethanol plant simplifies the effort to obtain high quality feedstocks.

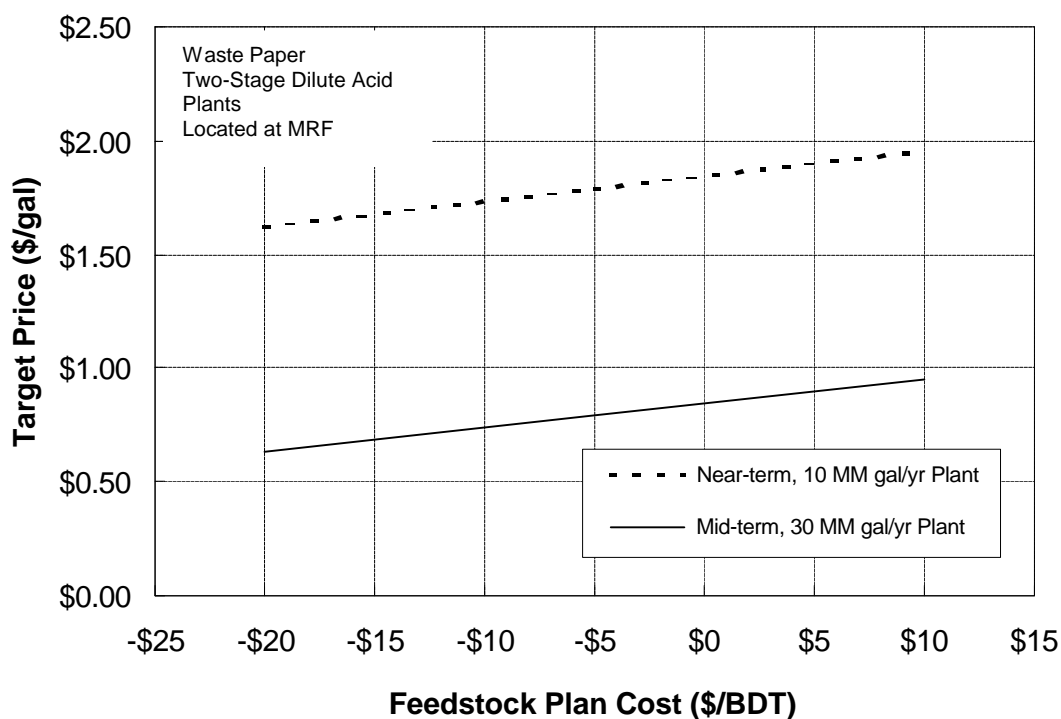


Figure VII-5. Relationship between waste paper feedstock cost and ethanol price.
Source: Appendix VII-B

Figure VII-6 shows prices of ethanol that would be economic in the mid-term for various feedstocks. Existing subsidies and tax credits on forest thinnings and rice straw significantly improve the economics of mid-term ethanol production. Increasing plant size also reduces production costs but the feedstock cost is the key consideration.

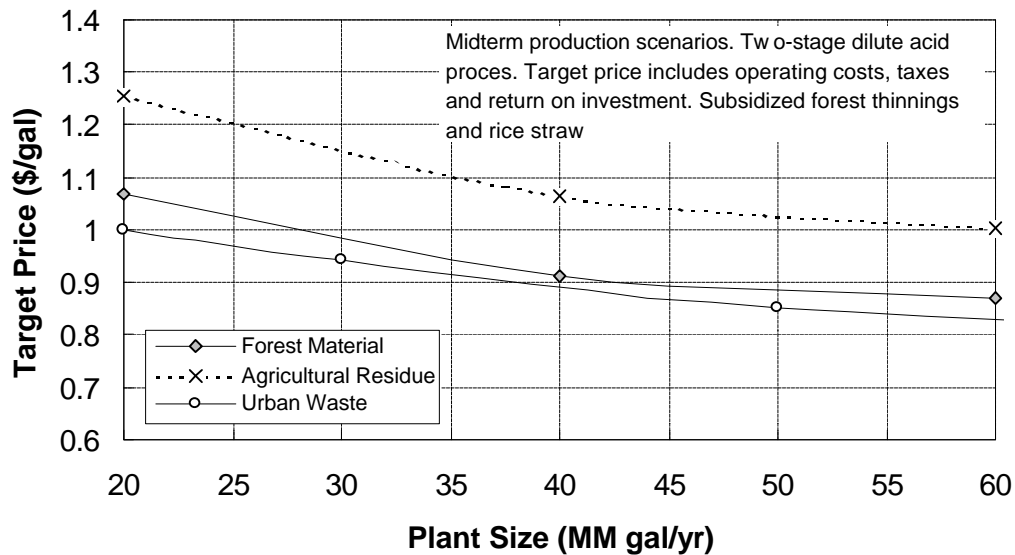


Figure VII-6. Effect of Plant size on economic ethanol price. Ethanol plants located with biomass power plants. Source: Appendix VII-B

Transportation costs also effect feedstock costs; the effect of transportation distance and related costs were included in the cost assumptions. It is unlikely that a plant operating on forest material would achieve economies of scale if the production rate exceeded 40 million gallons per year. Increased transportation distances and logistical issues related to securing feedstock supplies would increase the cost of forest material significantly. Constructing more plants in the 40 million gallon or smaller size range rather than larger plants would be optimal in terms of being able to process forest material over a wider area in California.

Transportation costs will likely limit agricultural and forest material plants more than other types of facilities since forest roads and spread out agricultural resources result in greater transportation distances. Transportation costs also increase with urban waste; however, the need to dispose of waste materials combined with the long distances already traveled for waste disposal could make urban waste materials available for larger plants.

Figure VII-7 compares the economics of feedstocks with and without subsidies. Subsidies have the greatest effect on the viability of plants operating on forest material, which is a high cost feedstock. If rice straw were not subsidized, it was assumed that more tree waste would need to be used as feedstocks for agricultural plants. However, less material would be available for ethanol production and fewer plants would be able to operate economically. The availability of subsidized rice straw is currently limited, which would be an obstacle for the economic production of ethanol.

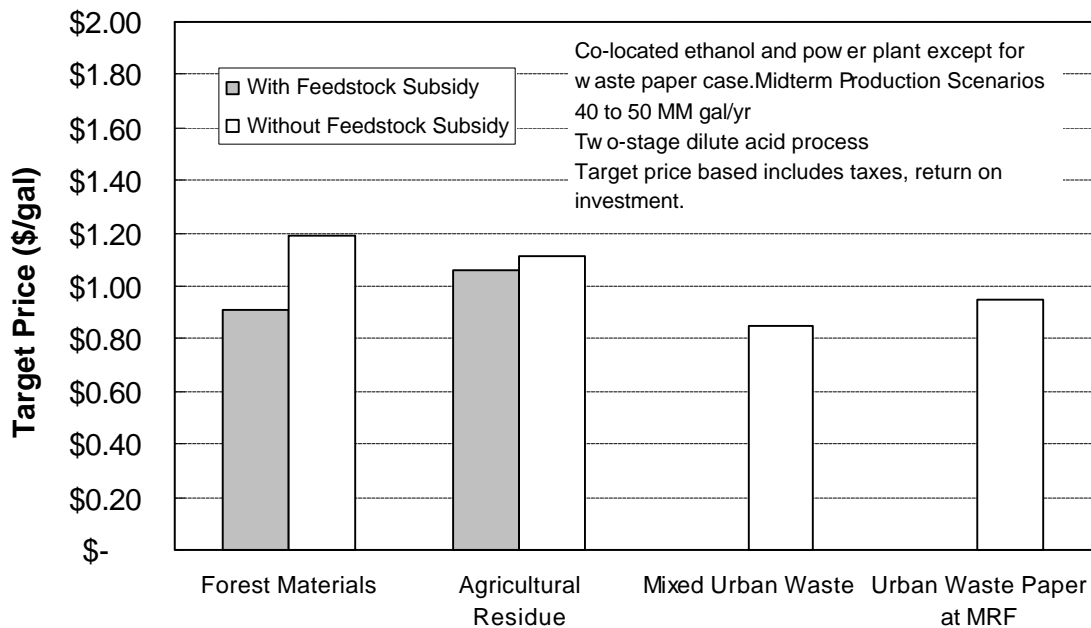


Figure VII-7. Effect of feedstock cost and subsidy. Source: Appendix VII-B

What are the Long-term California Ethanol Production Costs?

Over the long-term, ethanol production in California would evolve towards improvements in processing technology and additional feedstock resources. As experience is gained with cellulose based production, the net costs to produce ethanol are expected to be reduced because of increased ethanol yields, reduced enzyme costs, and the opportunity for additional value added coproducts. Additional feedstocks such as energy crops and additional urban waste materials may be economic. The cost of long-term ethanol production takes into account improvements in production technology and increased availability of feedstocks.

Figure VII-8 illustrates the effect of projected improvements in production yield and enzyme costs as ethanol production technology advances. The mid-term improvements in yield are very likely to occur as the same technology improvements are also underway in the paper and textile industries and are being applied to ethanol production with pilot plant developments. Near-term and mid-term plants were assumed to operate with subsidized forest material and rice straw with the subsidy removed in the long-term. Removing the significant subsidy on forest material in the long-term results in no change in the ethanol sales price as plant economics improve. Large plant sizes on the order of 80 million gallons per year for urban waste will also improve the economics of

ethanol production. It is likely that value added coproducts will enhance the economics of ethanol production. The effect of coproducts on the net ethanol price is discussed in the Appendix.

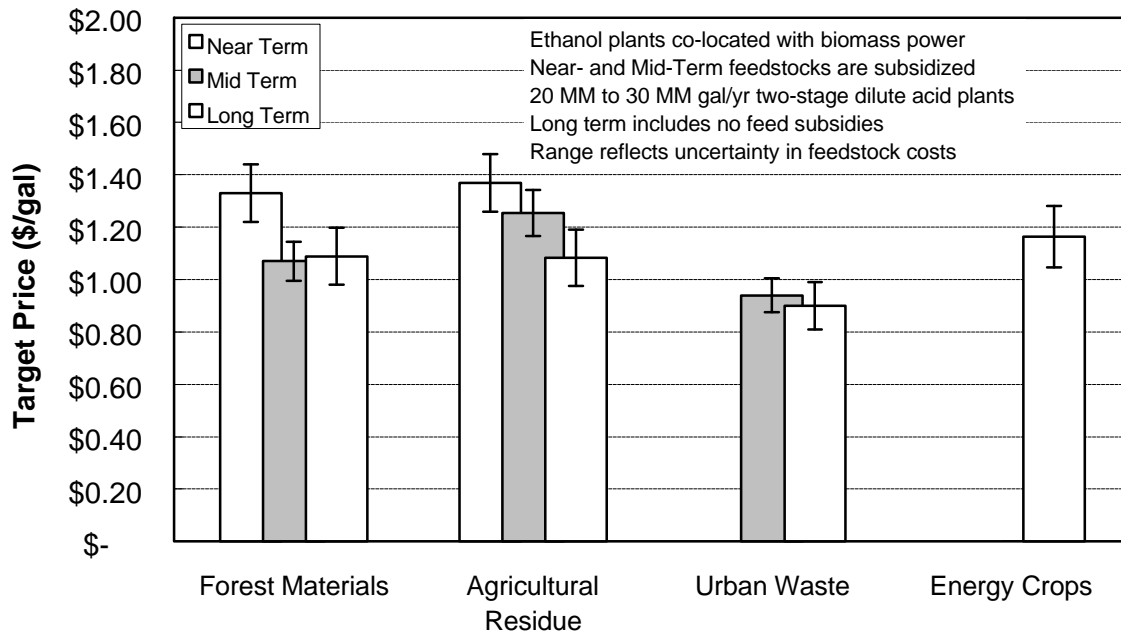


Figure VII-8. Economic ethanol prices decrease with advances in technology.
Source: Evaluation of Ethanol Production Costs, Appendix VII-B.

What is the Ethanol Supply/Cost Outlook from Out-of-State Sources?

Ethanol sources from out-of-state were examined in terms of the expected cost to produce ethanol. Also examined was the potential for these sources to meet the demand for increased or sustained ethanol in California in the longer-term.

Out-of-state sources were examined in terms of the expected price of ethanol. Also examined was the potential for these sources to meet increased or sustained ethanol demand for in California in the longer-term.

The delivered price of out-of state ethanol was determined by estimating its competing value as a gasoline blending component. Available production capacity, state-by-state pricing of gasoline, transportation costs, and state tax

credits determined the delivered price to California. A baseline gasoline wholesale price of \$0.62/gallon and MTBE price of \$0.85/gallon are assumed.

Figure VII-9 illustrates the intermediate-term supply curve for ethanol delivered to California. The available supply corresponds to price at which ethanol supplies in the Midwest and other states can be bid away from gasoline blenders in those regions. The breakeven price at which each state values ethanol was then matched with the corresponding volume of ethanol used by each state. Unused U.S. capacity as well as ethanol imported through the Caribbean was considered in the supply curve.

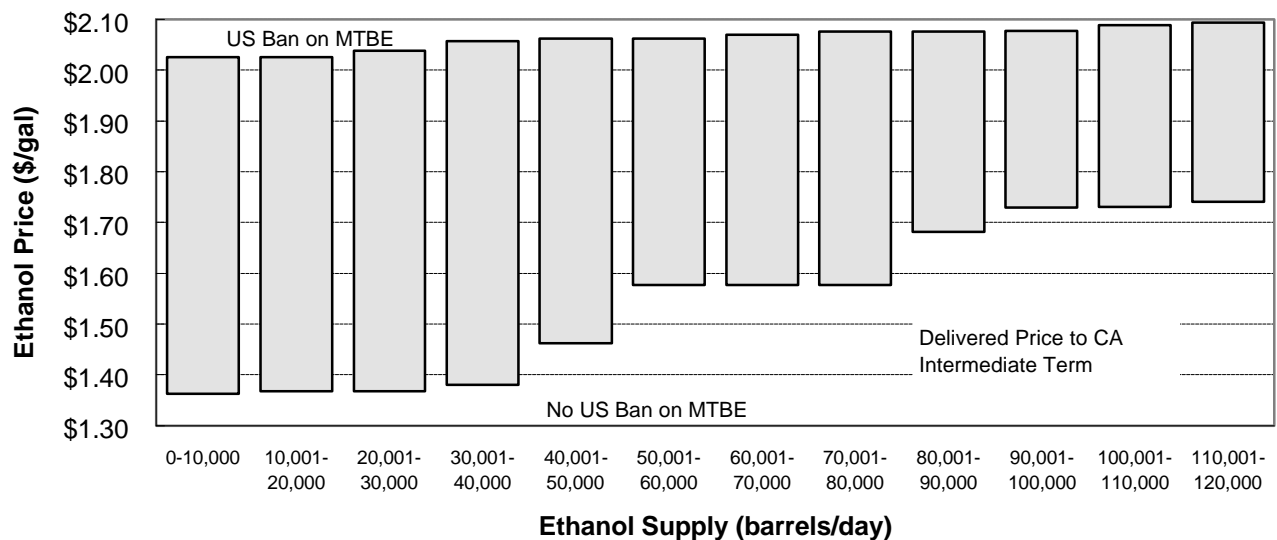


Figure VII-9. Intermediary Term Ethanol Supply Costs. Source: Appendix VII-C

The result is illustrated in Figure VII-9. For the first 10,000 bbl/day delivered to California, the price would range from \$1.36 to \$1.65/gallon depending upon whether the use of MTBE is banned in states other than California. If MTBE is banned throughout the U.S., the resulting intermediate-term cost curves for ethanol delivered to California will be correspondingly higher. Assuming the oxygenate mandate remains in place, blenders outside California would compete with California blenders for the existing ethanol supply. All ethanol in the U.S. would be valued as an oxygenate instead of as a lower value blending component for gasohol. For larger volumes of ethanol up to 120,000 bbl/day, the price increases to about \$1.70/gallon. These prices would decrease with a decrease in the price of gasoline.

This intermediate-term cost curve assumes that blenders outside California have access to the alternative oxygenates. If they must use ethanol as well, then there will be a substantial imbalance between demand and supply for ethanol. The resulting bidding war for the limited supply of ethanol cannot be determined from fundamental valuations alone, but the price spikes could be substantial.

The value of imported ethanol depends strongly upon the price of gasoline. Importing ethanol into California would require bidding up the price from out-of-state users where ethanol is blended with gasoline. If the price of gasoline is reduced, then the value of ethanol is also reduced. This effect is illustrated in Figure VII-10. Wholesale gasoline prices of \$0.42, \$0.62, and \$0.82 result in ethanol prices ranging from \$1.20 to \$1.50/gal for low levels of demand and \$1.57 to \$1.82/gal for higher levels of demand.

Lower gasoline prices would be a threat to a California ethanol industry as the sales price of competing ethanol would be reduced. Eliminating the \$0.54/gal federal tax credit would also reduce the price of ethanol delivered to California, if existing corn-based production facilities remain in operation. Without the tax credit, ethanol would be less cost effective as a blending component in gasoline and the price to California would drop to \$1.00/gal.

Long-term ethanol prices, shown in Figure VII-11, can be expected to moderate to the marginal cost of production. However, this ethanol production cost will increase as more corn is used to produce ethanol (increasing the price of corn) and as the by-products (such as distiller dried grains, gluten meal and gluten feed) drop in value due to their increased supply. A theoretical production cost was estimated using various assumptions regarding baseline corn costs and by-product costs. Corn elasticity values were corrected in this report relative to the previous CEC report, which increased the rate at which corn prices increase with added ethanol usage.

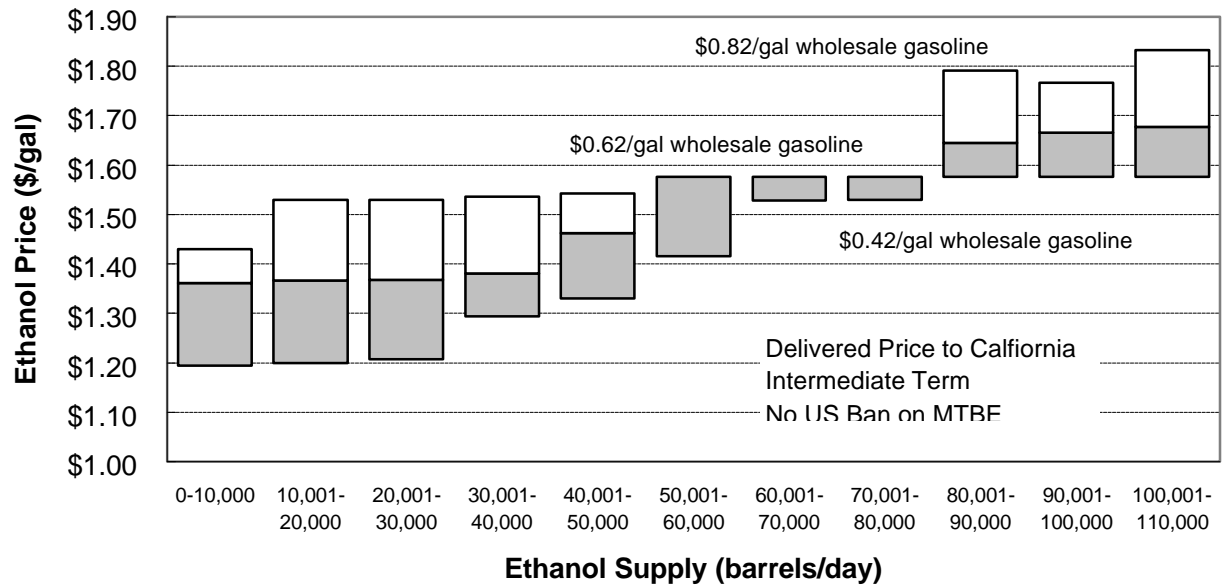


Table VII-10. Effects of gasoline price on delivered ethanol supply.
Source: Appendix VII-C

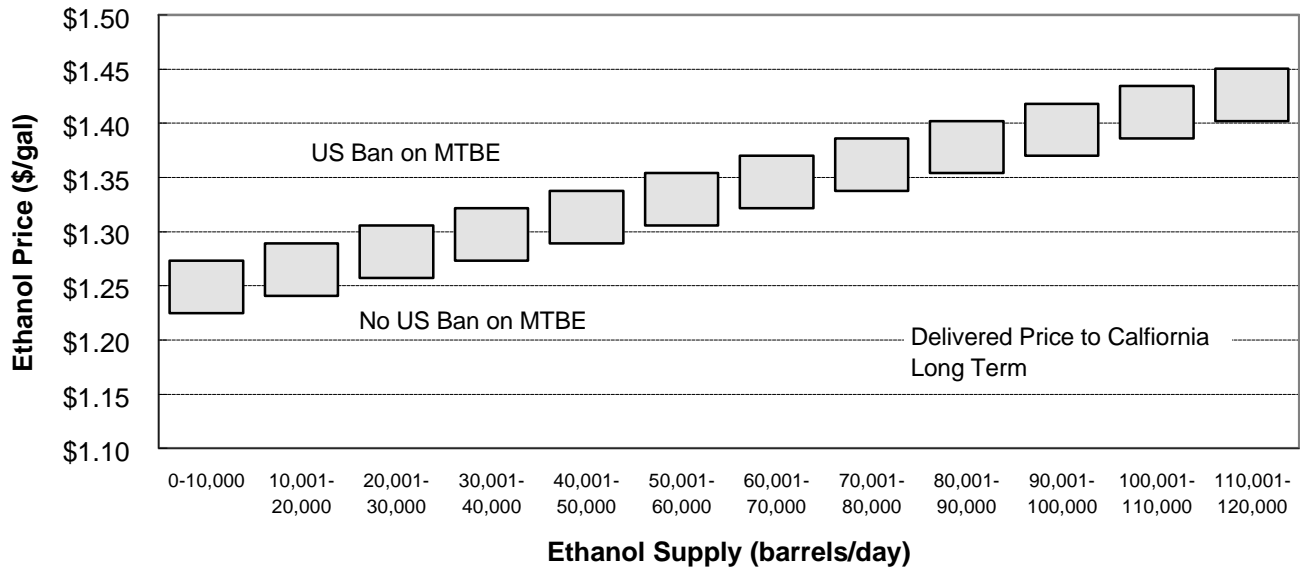


Figure VII-11. Long-term ethanol supply costs. Source: Appendix VII-C

The result is a supply curve which delivers ethanol to California at \$1.24 to \$1.27/gallon for the first 10,000 barrels per day. The price of ethanol delivered to California under a U.S. MTBE ban represents the upper range of the curve. Increasing the supply raises the price by \$0.20/gallon.

Ethanol from other sources has limited potential as a fuel. Synthetic ethanol, derived from the petrochemical industry does not qualify for the \$0.54/gallon federal tax credit so new supplies for vehicle fuel would not be likely. In Brazil, gasoline is required to contain 20 percent ethanol, so supplies are also limited. Trade agreements limit Caribbean ethanol to 10 percent of U.S. production. Therefore, corn based ethanol is the most significant source of ethanol for fuel uses.

What are the Economic Opportunities and Risk Factors Associated with a California Ethanol Industry?

The economic benefits associated with development of a California biomass-to-ethanol industry include:

- a) Support continued rice farming in the Sacramento Valley by providing a practical straw disposal alternative to burning.
- b) Help dispose of other agriculture wastes such as orchard prunings and agriculture crop residues.
- c) Reduce wild fire costs and losses by using forest wastes as a feedstock, decreasing the volumes of wildfire fuels.
- d) Improve air quality and, thus reduce medical costs associated with air pollution.
- e) Reduce ethanol imports into the state if ethanol is found to be an acceptable alternative to MTBE.
- f) Create jobs, new tax base and economic development in California.
- g) Create new biomass power revenues by collocating ethanol plants with existing biomass power plants. This improves the economics of biomass power production, enabling biomass power to better compete in California's new deregulated electricity markets.
- h) Reduces California's dependence on imported MTBE and related balance of payment.

Risks associated with development of a California biomass-to-ethanol industry include:

- a) The pace of biomass technology development will impact biomass ethanol production costs. A slower pace will result in higher ethanol production costs, which could adversely affect the California biomass ethanol industry.
- b) Biomass feedstock prices have a significant impact on the ethanol production costs estimated here. Higher feedstock prices could make California biomass ethanol less competitive with other sources of ethanol and restrict the size of the California ethanol industry.
- c) An ethanol market must exist in California if a large (over 100 million gallons/year) California ethanol industry is to develop. Without an ethanol market, it will be difficult if not impossible to finance new ethanol projects.
- d) The development of high value coproducts is anticipated to have significant impacts on ethanol production costs. There are technical and market risks associated with each coproduct that must be evaluated. For example, if the market for a coproduct is very small, then that coproduct may not have much of an impact on a large California ethanol industry.

References for Chapter VII

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